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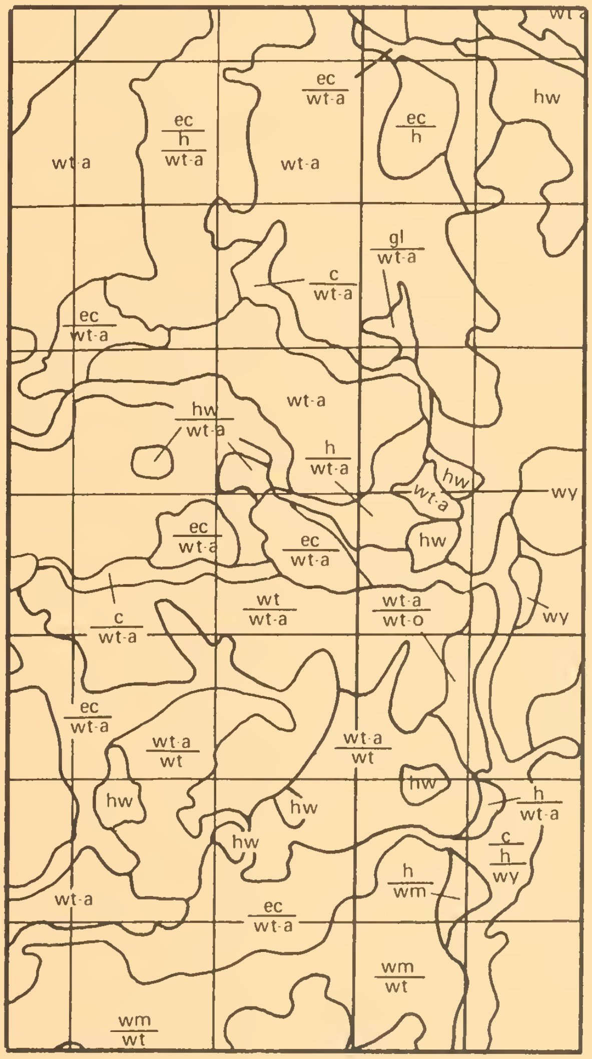
Three-dimensional geologic mapping for environmental studies in Illinois

John P. Kempton



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CONTENTS

1 ABSTRACT

1 INTRODUCTION

3 EVOLUTION OF STACK-UNIT MAPPING

- Multiple classification of glacial deposits
- Subsurface stratigraphic studies
- Data on physical and mineral properties
- Pleistocene Stratigraphy of Illinois
- Land use and environmental geologic studies
  - Early county and local studies
  - Recent county and regional studies

12 MAPPING PRINCIPLES AND PROCEDURES

- Establishing the stratigraphic framework
- Collecting and using data
- Determining depth limit
- Establishing criteria for defining stack units
- Using conventions with stack units
- Preparing stack-unit maps

27 PRESENTING THE STACK-UNIT MAP IN FINAL FORM

- Map unit complexities and the scale problem
- Use of color and pattern

29 USES FOR STACK-UNIT MAPS

- Geologic interpretation
- Interpretation for applied uses
  - Waste disposal
  - Land treatment
  - Construction (engineering) conditions
  - Development of mineral resources
- Coordination with pedologic soil maps

33 POTENTIAL LIMITATIONS TO STACK-UNIT MAPPING

- Lack of data
- Scale problems
- Complex geology
- Extreme topographic relief
- Problems of presentation

35 POTENTIAL FOR FURTHER DEVELOPMENT

- Mapping to greater depths
- Mapping unglaciated areas
- Preparing terrain maps
- Preparing detailed mapping for site studies
- Incorporating soil data on stack-unit maps

38 SUMMARY

39 REFERENCES

ACKNOWLEDGMENTS

It is frequently the case that new approaches and methods are a result of input, over many years, from numerous sources and individuals; this has certainly been true for the development of the stack-unit mapping concept. Many staff members of the Illinois State Geological Survey have contributed to the development of stack-unit mapping over the past 15 to 20 years, but the contributions of J. E. Hackett, D. L. Gross, L. R. Follmer, and P. B. DuMontelle have been particularly significant in the development of the specific methods described in this report. Their work and the work of others outside the Survey are acknowledged in the text.--JPK

ABSTRACT

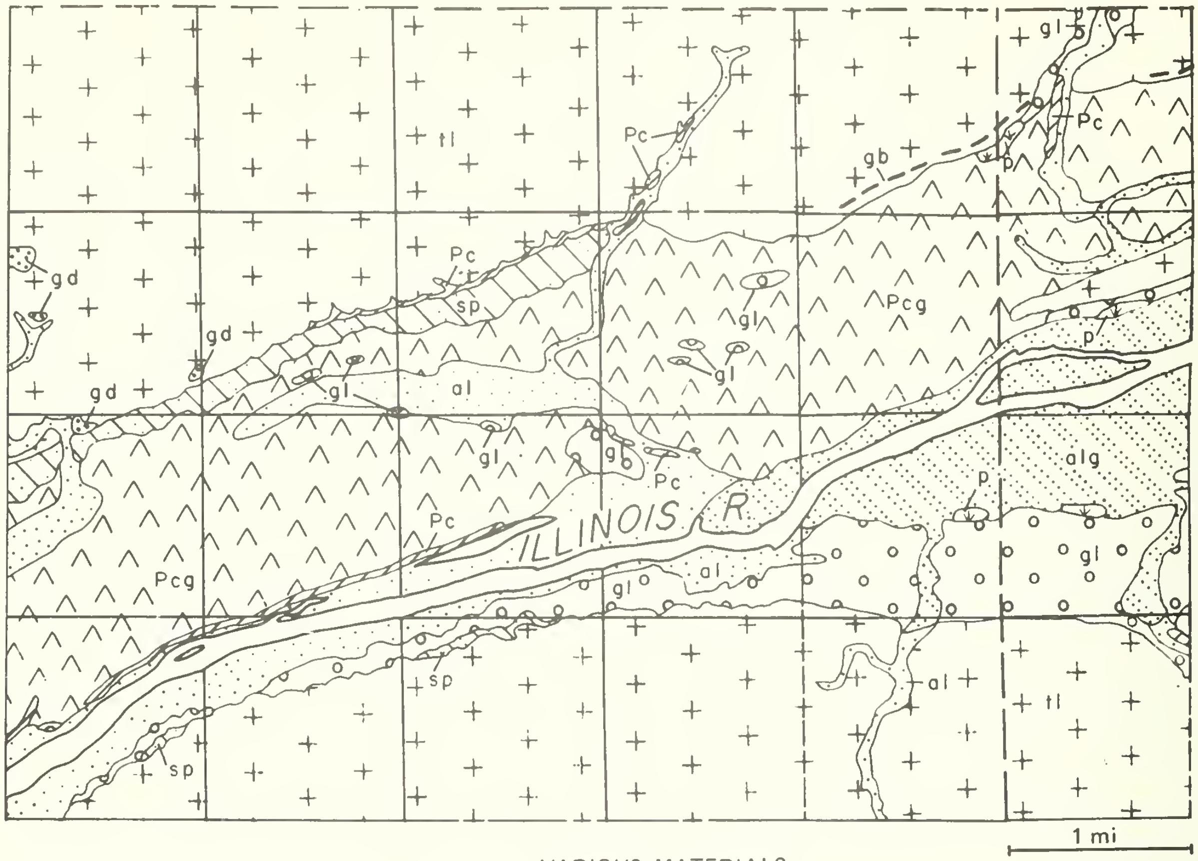
Stack-unit maps show the geologic framework of an area in three dimensions, depicting not only the areal distribution of geologic deposits and formations, but also their vertical distribution from the ground surface to a designated depth. The map may be presented as an outline map with each stack unit labeled within the limit of its boundary, by some simple arrangement of color and/or pattern indicating both surface and subsurface units, or by some combination of labels, colors, and patterns. The technique for preparing three-dimensional stack-unit maps has evolved over the last 20 years and is currently a method for depicting the surficial and near-surface deposits of Illinois at the Illinois State Geological Survey. Interpretive maps for most geologic, land use, and resource evaluations can be made directly from this basic stack-unit map, given the physical and mineralogical properties for each unit and a set of criteria for each interpretative map.

INTRODUCTION

Detailed geologic information about materials at and near the surface of the earth is routinely needed in Illinois for assessments of waste disposal sites and construction conditions, studies of shallow ground water availability and artificial recharge, and development of sand and gravel and other mineral resources. It has become increasingly clear that most conventional maps of surficial deposits, which show geological units at a given surface but do not indicate the thickness or depth of these units, cannot always provide the basic information required for many of these purposes.

Within the last 15 years, the increasing demand for maps that provide direct information for a particular resource or land use (interpretative maps) has stimulated the development of a type of map that shows geologic materials in three dimensions. This type of map, herein called a stack-unit map, provides information on the probable occurrence of one or more geologic materials to a given depth over a specified area. Therefore, in addition to showing principal surface deposits, a stack-unit map also indicates the materials that occur below the surficial material to a given depth (for example, to 20 ft or 6 m). Each individual stack unit shown on the map represents a unique succession of mappable rock-stratigraphic/soil-stratigraphic units down to the depth limit.

The value of such a map is that it includes (in a convenient, immediately comprehensible format) information on the area, depth, and thickness of all geologic materials significant for many specific uses. From such a map, accurate interpretive maps for land-use planning and resource development can be prepared with comparative ease.



VARIOUS MATERIALS

Pcg — Thin sand and gravel overlying sandstone, shale, clay, coal, and limestone; as much as 125 feet thick. No. 2 Coal and overlying strata. (Carbondale Formation)

DOMINANTLY SILT AND CLAY

(Mostly poorly sorted and unsorted materials)

al — Alluvium. Deposits of modern rivers and streams in floodplains. Largely clayey silt, generally less than 20 feet thick. Contains lenses of sand and gravel, especially in lower part. (Cahokia Alluvium)

alg — Thin alluvium, as above, overlying thick deposits of sand, sandy gravel, and fine gravel. (Cahokia Alluvium on Henry Formation)

sp — Slopewash. Steep-sloped lenticular deposits along the base of bluffs, including many small alluvial cones and fans. Largely clayey and pebbly silt containing bedrock fragments and glacial drift materials; all washed and slumped from adjacent bluffs. Generally less than 20 feet thick. (Peyton Colluvium)

tl — Till. Mostly unsorted calcareous pebbly silty clay deposited by glaciers. Contains scattered cobbles and boulders and, in places, lenses of sand and gravel. Includes small gravel hills (kames and deltas) on the Marseilles Moraine. Generally 25-50 feet thick but 100-150 feet in the Marseilles and Minooka Moraines. The till has a thin cover of clayey silt (Richland Loess and Equality Formation), as shown on the small inset map. (Wedron Formation)

GRAVEL AND SAND

gh — High-level terraces underlain by glacial outwash. Surfaces are 50-75 feet above the Des Plaines River. In the eastern part of the district, mostly fine gravel and sand. Thickness varies—it is as much as 80 feet in the Channahon area and as much as 40 feet in the Drummond area. In the western part of the district, the deposits are largely cobbly coarse gravel and fine gravel, commonly 20-25 feet thick. (Henry Formation)

gl — Low-level terraces and bar-like ridges underlain by deposits of the Chicago Outlet River. Surfaces are 20-30 feet above the Des Plaines and Illinois Rivers. Mostly medium to coarse gravel, commonly 10-40 feet thick. Above Dresden Island Dam these deposts generally rest on Ordovician and Silurian bedrock. From the dam to Stockdale, 3 miles west of Morris, they commonly overlie sandy gravel and coarse, medium, and fine sand. Bouldery gravel occurs in small deposits west of Goose Lake but is not known to be more than 15 feet thick. West of Stockdale the gravel occurs in bar-like ridges and scattered thin deposits on Pennsylvanian age sandstone or shale. (Henry Formation)

gb — Beach deposits along the Cryder Lake shoreline. Sandy gravel with scattered cobbles and boulders in a discontinuous ridge at the top of an erosional escarpment at an elevation of 540 feet along both sides of the Illinois Valley near Morris. (Equality Formation)

FIGURE 1. Part of surficial geology map of the area bordering the Illinois waterway, Morris District (Willman, 1973, from plate 1).

This report focuses specifically on the development of stack-unit mapping of the glaciated portions of Illinois, discussing techniques for preparing and presenting stack-unit maps, uses of three-dimensional maps, limitations to the method, and the potential for further development. Although three-dimensional mapping is potentially applicable to all types of geology, in Illinois it has so far been applied primarily to glacial and glacial-related deposits.

EVOLUTION OF STACK-UNIT MAPPING

Three-dimensional geologic mapping is not a new idea. In the 1960s, the Netherlands Geological Survey developed a type of three-dimensional mapping tailored to their specific geologic conditions (Hageman, 1963; Thiadens, 1970). The maps produced by this mapping technique (called profile-legend maps), were very complex, requiring a large number of color and pattern combinations to show the details of subsurface relationships (Varnes, 1974; Hageman, 1962; Rummelen, 1965). The profile-legend approach was also used a few years later by Lutzen and others at the Missouri Geological Survey to show two- or three-story units for engineering geologic maps (Rockaway and Lutzen, 1970); such a system has since been formalized for use in engineering and environmental geology (Galster, 1977) and a similar type was used by Matula (1969).

Until recently, however, most efforts to show strictly geologic units three-dimensionally have generally been indirect. Most geologic maps show units at a given surface (land surface, subloess surface or bedrock surface), but provide little direct indication about the thickness of these units or the depth to which the mapped units extend at any given point on the map. Such information has generally been supplied on separate thickness maps, structure maps or other contour maps, cross sections, and expanded legend or text descriptions. Willman (1973), for instance, mapping the geology of the Illinois River Valley, showed certain multiple map units and, in the legend, supplied thickness data for some units within the Valley (fig. 1; note map legend for units al, alg, and gl).

It is generally within the uppermost 20 feet (6 m) of the earth's surface that most ordinary human activities are concentrated. In Illinois most of the surficial and near-surface materials are glacially derived and normally have much greater lateral and vertical variation than do the underlying bedrock formations; therefore, it is these glacially-derived deposits that must be mapped and characterized in detail.

The current use of three-dimensional mapping in Illinois is an outgrowth of a series of developments occurring over many years and involving many geologists. These developments included (1) a philosophical change, based

on current needs, in the general approach to glacial geology--which resulted in the multiple classification of glacial deposits and the formal classification of Illinois glacial deposits; (2) greater recognition of the value of subsurface data in characterizing glacial deposits--which stimulated the development of new techniques to obtain and analyze subsurface data; and (3) increased concern about environmental problems--which created a demand for more precise information on the character and distribution of surficial geologic materials for land-use planning and environmental geology.

Multiple classification of glacial deposits

Before 1958, Pleistocene glacial and associated deposits in Illinois were described and mapped under a single classification system that did not include the identification of formations, members, and other rock units. Glacial moraines were treated essentially as time units, although in practice they were mapped and described as rock units. As a result, maps of Pleistocene deposits did not always provide the kinds of information on the distribution of materials with similar properties currently considered most useful for resource development and land-use interpretations.

In 1958, the Illinois State Geological Survey presented a revised classification (Willman, Swann, and Frye, 1958) specifying that Pleistocene deposits be classified by the same principles as all older parts of the rock column, and in 1961, the American Commission on Stratigraphic Nomenclature presented its proposed stratigraphic code for North America (A.C.S.N., 1961). Both schemes established multiple hierarchies of classification in which Pleistocene deposits were included. Each classification was independent of the other and had distinguishing names to prevent confusion between the two. In 1970, Willman and Frye developed a system of multiple classification for the Pleistocene deposits of Illinois: their recognition of four separate classification schemes (rock-stratigraphic, soil-stratigraphic, morphostratigraphic, and time-stratigraphic) provided the basis for the development of the current generation of geologic materials maps.

Subsurface stratigraphic studies

Subsurface investigations have played a key role in establishing the rock-stratigraphic (materials) framework of the glacial deposits in Illinois and in providing data for stack-unit mapping. Many early geologists in Illinois recognized the importance of using subsurface information to extend the knowledge of glacial deposits gained from the study of surface exposures

(Leverett, 1899). Subsurface data used before 1960 consisted principally of water-well logs and samples, supplemented by some data from oil and coal tests, shallow hand-auger boring records produced during field studies (Leighton, 1923; Shaffer, 1956), and field notes. Some information was also available from foundation boring logs and samples from engineering studies collected by George E. Ekblaw and W. Calhoun Smith of the ISGS Engineering Geology Section. Of particular significance was the work of Horberg (1950, 1953), Otto (1942), and Peck and Reed (1954). Horberg conducted the first of the modern subsurface stratigraphic studies, and Otto and Peck and Reed established the significance of foundation and engineering borings as important sources of data for stratigraphic work and mapping as well as for foundation engineering. Kempton and Hackett (1962) proposed that logs, data on physical properties, and samples from engineering borings and foundation investigations be used as a source of data on physical properties for stratigraphic study and correlation of glacial deposits. Kempton (1963), Kempton and Hackett (1968), Landon and Kempton (1971), and others have further developed the use of subsurface data for characterization of individual stratigraphic units. Representative samples from engineering borings and logs and engineering property data from many engineering projects in Illinois have been collected and filed at the ISGS for more than 20 years.

Several major controlled drilling programs directed by the Geological Survey (Hackett and Hughes, 1965; Reed, 1972; and others) have provided significant regional subsurface data. The Survey's drill rigs are now used in such studies, a factor that has greatly improved the potential for three-dimensional mapping. As the subsurface data base has grown, so has the Survey's ability to define more precisely the thickness of surficial units and map the distribution of subsurface units--two of the principal requirements for producing three-dimensional maps.

Data on physical and mineralogical properties

Two developments significantly increased the ease and speed with which the ISGS could obtain large quantities of data on the various materials to identify, characterize, and correlate them. Of particular importance was the use of x-ray diffraction techniques developed over the past 25 years by H. D. Glass for characterizing the clay mineral and carbonate composition of till and loess deposits (Frye, Glass, and Willman, 1962; Willman, Glass, and Frye, 1963; Kempton and Hackett, 1962; and Kempton, DuMontelle, and Glass, 1971). Also important was the use of routine hydrometer techniques for grain-size analysis of the glacial tills. The use of grain-size analyses to characterize tills was first described by Krumbein (1933) and later used by Wascher and Winters (1938) and Shaffer (1956) for distinguishing between the

different surface till sheets in Illinois. More recently both methods have been applied to subsurface studies (Kempton, 1963; Kempton and Hackett, 1968; Landon and Kempton, 1971; and others) as well as to surface sampling and mapping. Although physical property data have been available from engineering projects for more than 30 years, they have not always been used in a geologic context. Once this context was established, however (Landon and Kempton, 1971), physical property data from Pleistocene deposits was used increasingly for predicting conditions for engineering projects (Peck, 1968) and for correlation of geologic materials.

Pleistocene Stratigraphy of Illinois

Pleistocene Stratigraphy of Illinois, by H. B. Willman and John C. Frye (1970), culminated about 10 years of intensive study of the Pleistocene deposits of Illinois and summarized information on Illinois surficial deposits collected by geologists over a period of 100 years or more. This report established a framework for the Pleistocene deposits and presented a basic rock-stratigraphic classification of these deposits.

In addition to establishing the conceptual framework of the Pleistocene materials, the report also established a complete set of names for all rock-stratigraphic (material) units identified in Illinois at that time. This nomenclature helped eliminate the confusion that had prevailed previously because of inconsistencies in the use of map units. The names established for each rock-stratigraphic unit became available for all new mapping in Illinois, providing consistency in the recognition of each unit wherever it occurs. Each defined rock-stratigraphic unit occurs in a distinct stratigraphic position and has a distinctive set of physical and mineralogical properties; with proper identification of these units, adjoining map areas should be compatible.

Land-use and environmental geologic studies

Establishment of the environmental geology program at the Illinois State Geological Survey (by 1965) was probably the single most important catalyst for the evolution of three-dimensional mapping in Illinois (Hackett and Hughes, 1965; Hackett, 1967; Larsen and Hackett, 1965; and Frye, 1967). To provide the geologic information required for various local, county, or regional land-use or resource development studies, the ISGS normally supplied data on both surficial materials and materials to various depths. This information--which usually included a surficial deposits map, drift thickness maps, a geologic map (showing bedrock formations), and detailed text descrip-

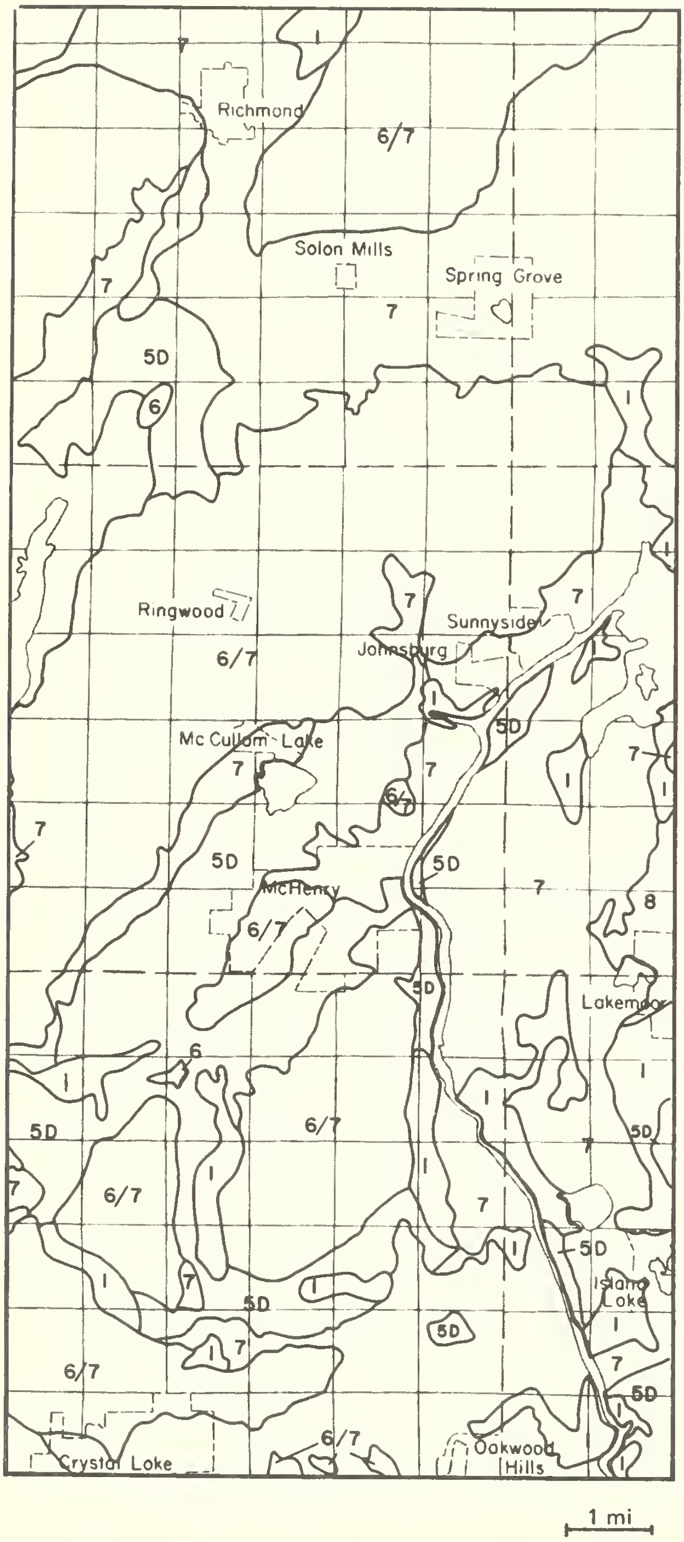
tions--was apparently considered sufficient for most purposes. But as concern about the environment began to increase, a number of county and regional planning commissions were organized--and these agencies wanted simple geologic- or soils-based interpretive maps that would provide immediate guidelines for such questions as where they could (or could not) safely locate a landfill or new power plant (Quay, 1966, 1968). It soon became obvious that a change in the way geologic information was presented might be in order.

Conventional geologic or surficial deposits maps can be interpreted directly for some uses (USGS, 1949), particularly by geologists familiar with the geology of a specific area. However, information on the thickness and depth of earth materials--not directly available from such maps--is necessary for many purposes. For instance, criteria for a solid waste disposal project may require that there be a layer of less permeable material of specified thickness separating the base of the waste from the top of a ground-water reservoir (aquifer) below. Information on the thickness of overburden as well as the thickness of the resource is needed for evaluating the economic potential of sand and gravel resources. And information on depth and thickness of materials is also necessary for engineering projects such as cuts, foundation or basement excavation, depth to adequate bearing strength, and so on. The need to prepare geologic maps that would be more immediately useful for such projects suggested some different approaches to mapping (McComas, Hinkley, and Kempton, 1969).

Early county and local studies. One of the first environmental geology reports produced at the ISGS was Geology for planning in Mc Henry County (Hackett and McComas, 1969). This publication set the course for subsequent projects in the program by (1) presenting geologic information in a nontechnical fashion; (2) providing a three-dimensional surficial geologic map (fig. 2) that included subsurface information; and (3) including interpretive maps showing resources and geologic conditions critical for certain uses of land (waste disposal and construction). The three-dimensional approach to surficial mapping was partly a consequence of the particular conditions in McHenry County—specifically, large areas of thin till overlying sand and gravel. It appeared that an earth materials framework (the spatial arrangement of geologic deposits differentiated primarily on the basis of composition and physical properties) could be conveniently developed as a basis for interpretive or evaluative maps. The delineation of areas of till over sand and gravel would have more significance for land-use planning than would the simple mapping of till. The unit "6/7" (fig. 2) and similar relationships that could be shown were the result.

In a subsequent report, Geology for planning in De Kalb County (Gross, 1970),

FIGURE 2. Part of surficial deposits map of McHenry County, D. L. Gross (Hackett and McComas, 1969).



SYSTEM	Series	Stage	Substage	Unit	
QUATERNARY	Pleistocene	Recent			1 Peat
		Wisconsinan	Woodfordian	West Chicago	5D Sand, variable 6 Till, yellow, sandy, gravelly, >5 feet thick 6/7 Unit, <5 feet thick, over sand and gravel 7 Sand and coarse-grained gravel
				Marseilles	8 Lacustrine clay (Lake Wauconda)

the stack-unit concept was adopted, and another element was added: the establishment of a depth limit to which the units were mapped (fig. 3). For this project, a depth of 20 ft (6 m) was selected, for the very practical reason that this was the depth for which the most definitive data were available. With this report, all the basic elements currently used in stack-unit mapping in Illinois were established. Another report, Geology for planning at Crescent City (Bergstrom, 1970), which utilized the same mapping principles, was published shortly thereafter.

Recent county and regional studies. No similar maps were published during the next six years, but studies leading to further development of three-dimensional mapping were underway. Then with the publication of Geology for planning in the Springfield-Decatur region, Illinois (Bergstrom, Piskin, and Follmer, 1976), two innovations--the use of thickness notations for the surficial loess units and the incorporation of soil-stratigraphic units within the stack-unit sequence (fig. 4)--were added to the stack-unit con-

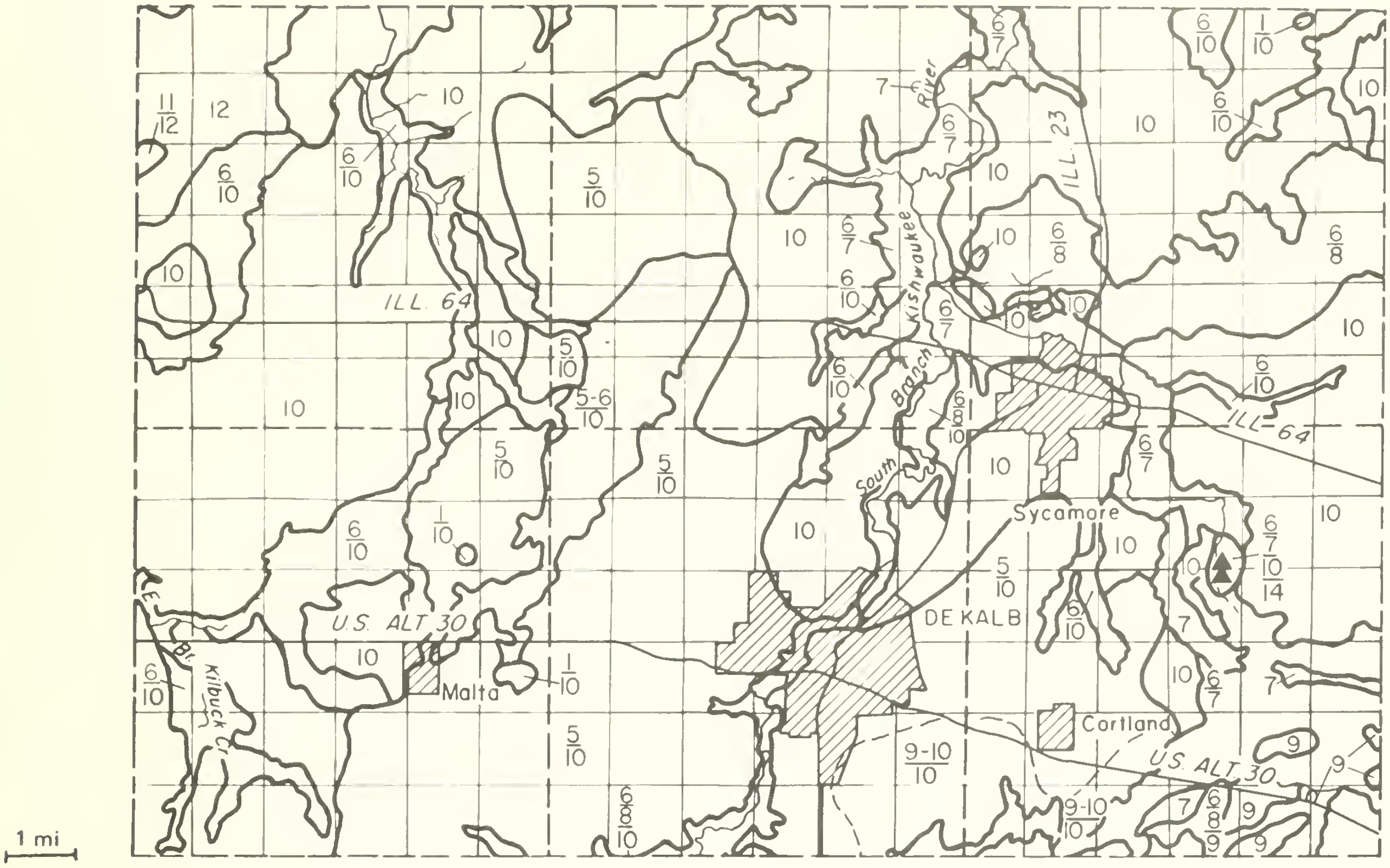


FIGURE 3. Surficial deposits of De Kalb County, mapped to a depth of 20 feet, John P. Kempton (Gross, 1970).

Unit	General category	Material
1	Organic sediments	Peat and muck
	Ablation and ice-contact deposits (late glacial and post-glacial deposits)	
5		Elevated flat-topped mounds composed principally of silt with some interbedded sand and gravel, >5 feet thick; local areas of underlying till exposed between mounds
6		Lacustrine and alluvial silt and sand deposits (includes areas of Unit 2 along principal streams not differentiated at present)
	Glacial outwash (includes some ice-contact deposits)	
7		Medium- to coarse-grained gravel and sand; small hills of Unit 7 not mappable at present scale are indicated by X
8		Sand with fine gravel, in part poorly sorted
	Glacial till	
9		Elburn till - yellowish brown, tan to gray, sandy, silty, frequently quite gravelly; local inclusions of sand and gravel and pink till
10		Bloomington till - pink, reddish brown to reddish gray, sandy silt, somewhat more clayey than Unit 9, uniform
11		Esmond till - yellowish brown, brownish gray to gray, clayey silt to silty clay, often somewhat sandier near top
12		Capron till - reddish brown to pinkish gray clayey silt to silty clay, locally sandy at top
13		Argyle till - pinkish brown to pinkish gray, gravelly sand, hard, compact
	Bedrock	
14		Alexandrian (Silurian) dolomite

cept. These additions supplied important information on the geologic materials map for an area where the thickness of the loess was significant but varied widely and the buried Sangamon Soil had greatly modified the characteristics of the materials in which it developed.

The next year another approach to presenting three-dimensional maps was added in Geology for planning in De Witt County, Illinois (Hunt and Kempton, 1977). In this report, discontinuous beds within the mapping depth of 20 ft (6 m) were

WISCONSINAN			
WOODFORDIAN			
Peoria Loess			
p	p4	p7	p10
Silt, 60%-85%, 5%-15% sand, 15%-40% clay, 0%-2% gravel; locally colluvial; weathered; all in Modern Soil.	Silt, 60%-85%, 4%-12% sand, 10%-40% clay, 0%-1% gravel; weathered; mostly in Modern Soil; in a few areas, lower 1-3 ft is calcareous.	Silt, 60%-85%, 3%-10% sand, 10%-40% clay, 0%-1% gravel (concretions); weathered; upper 5-7 ft in Modern Soil; lower 3-4 ft normally calcareous.	Silt, 60%-85%, 2%-8% sand, 5%-35% clay; concretions common below soil; upper 4-7 ft in Modern Soil; lower 8-11 ft calcareous; locally carbonates are present 2-3 ft below surface.
0-4	4-7	7-10	10-15

† During the Sangamonian Stage the Sangamon Soil was formed on Illinoian and older deposits. The Sangamon Soil is shown by the symbols zs, zs-g, and zs-ox. The letter "z" identifies a stratigraphic unit as a soil, not a rock unit. In most cases the parent material for the soil is the underlying Illinoian deposit. The following table explains the general characteristics of the Sangamon Soil as delineated on the map.

Type	Symbol	Description	Thickness (ft)
Sangamon Soil	zs	Sandy clay: 20%-40% sand, 30%-40% silt, 25%-45% clay, 1%-10% gravel; locally may be coarser or finer; undifferentiated weathered deposits that include zs-ox, zs-g, and Berry Clay.	3-10
Sangamon Soil, gleyed	zs-g	Sandy clay: 20%-30% sand, 30%-40% silt, 30%-45% clay, 1%-3% gravel; locally finer; montmorillonitic; green, blue, or gray poorly drained Sangamon Soil; undifferentiated weathered deposits that include Berry Clay.	3-10
Sangamon Soil, oxidized	zs-ox	Sandy clay: 30%-40% sand, 30%-40% silt, 20%-40% clay, 2%-10% gravel; locally coarser; yellow, brown, or red imperfectly drained to well-drained Sangamon Soil; undifferentiated weathered deposits.	4-10

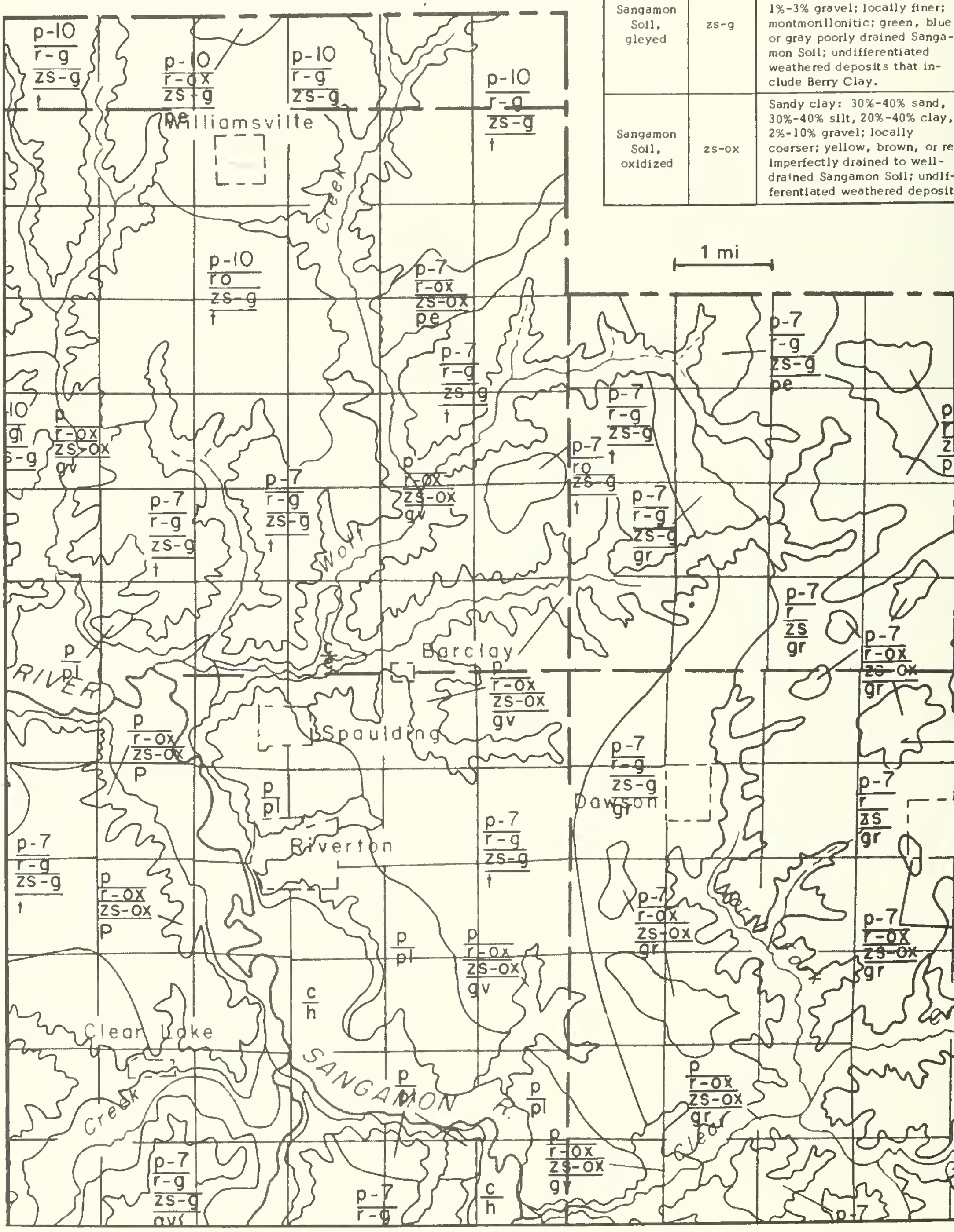


FIGURE 4. Part of surficial materials map of Springfield-Decatur region, Illinois, Leon R. Follmer, Robert M. Mason, and Kemal Piskin (Bergstrom, Piskin and Follmer, 1976, plate 1).

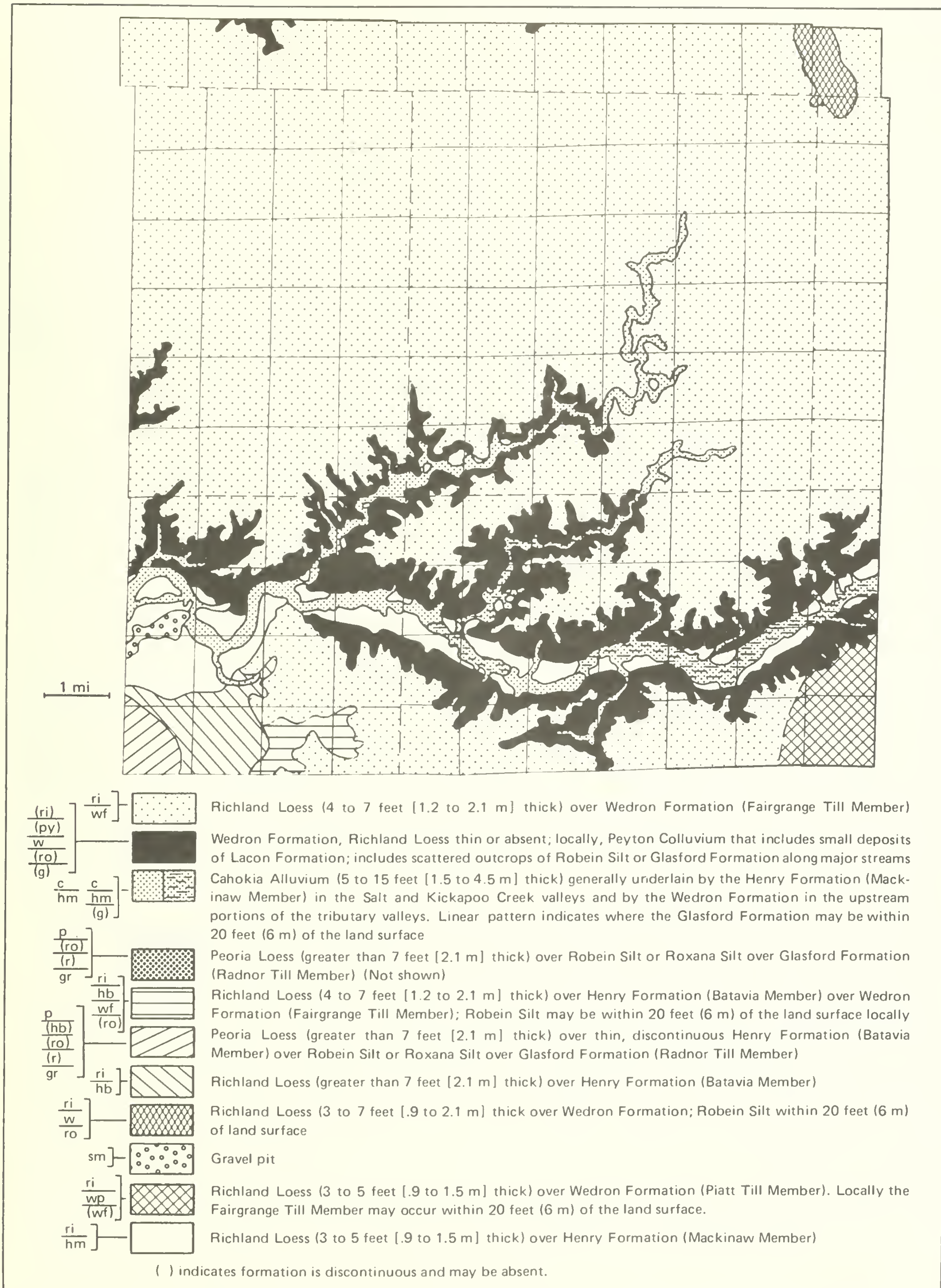


FIGURE 5. Geologic materials to a depth of 20 feet, De Witt County, Illinois (Hunt and Kempton, 1977, fig. 6).

indicated on the geologic materials map (fig. 5) by enclosing in parentheses the symbols representing those beds. This map, the first ISGS stack-unit map published in color, was an attempt to present complex local areas at a small scale—in a more generalized fashion—without sacrificing the presentation of useful information. For this map, the more complex areas along Creek Valley walls were lumped into complexes. All stack units mapped were then represented by a color and shown in the legend.

In 1975, a study conducted in cooperation with the Northeastern Illinois Planning Commission (NIPC) established the importance of three-dimensional mapping of geologic materials and provided the model for procedures currently used in three-dimensional mapping. The study involved comprehensive geologic mapping of the six-county Chicago metropolitan area and preparation of interpretive maps indicating the pollution potential of various waste disposal and land treatment practices, as well as other land-use and resource evaluation. The basic mapping for this work was completed in 1976; the following year, study results were summarized by Kempton, Bogner, and Cartwright (1977).

The basic mapping for this project was (1) compiled at a scale of 1:24,000 on USGS 7½-minute topographic quadrangle maps (fig. 6); (2) reduced to a scale of 1:62,500 and transferred to county base maps for preparation of interpretive maps for each county at that scale; and (3) finally reduced to a scale of 1:125,000 and compiled on a regional base for the six-county summary (fig. 7). Several practices (conventions) now routinely used with stack-unit maps were first adopted in this study. In addition to showing discontinuous units by enclosing the symbols for those units in parentheses, another new convention allowed recognition of additional material units of facies that are unnamed subunits of formations or of submember rank by adding, to the named unit symbol, a hyphen and a letter designation for the unnamed unit (for instance, wt-a, for ablation drift of the Tiskilwa Till Member).

MAPPING PRINCIPLES AND PROCEDURES

The geologic map is the basic building block upon which information on the distribution of the various types of rocks and other earth materials is organized and conveyed to the user. In one of its simplest forms, a geologic map shows the occurrence and physical boundary of each type of rock or material and their relationship to other types of material at the earth's surface. This information is normally superimposed upon a base map to show the relationship of the materials to surface or cultural features so that the map provides an indication of the type of materials occurring at any location on the map. The accompanying map legend or text explanation usually includes a

brief description of the map units and indicates the relative position of the mapped materials. The legend also may provide information on the thickness, extent, and age of each map unit and may include a statement as to the accuracy of the boundaries.

The complexity of a geologic map depends on the intended use of the map, the complexity of the geology to be mapped and the scale at which it was mapped, and the scale at which the final map will be printed.

The most common geologic maps utilize the lithologic or rock-stratigraphic classification, of which the formation is the basic unit. (A formation is a mappable lithologic unit which covers a relatively large area and can be recognized by common field criteria.) Subdivisions of the formation (member, bed, etc.) can be shown if the scale permits, and other classifications (such as time-stratigraphic, morphostratigraphic) can also be used. However, basic mapping requires the use of some type of lithologic classification, particularly when land-use characteristics are to be determined from it.

Most geologic maps are two-dimensional, showing only the areal distribution of materials at land surface or at some selected depth interval. (For example, the Geologic Map of Illinois [Willman, 1967] shows the areal distribution of the various bedrock units directly below the overlying glacial deposits.) Since geologic materials are three-dimensional, adding the vertical dimension to geologic maps obviously increases the usefulness of these maps. However, there are a number of problems connected with producing three-dimensional maps, involving both the preliminary mapping and the subsequent presentation of the information in a useful format. Certain principles and procedures have been established to help overcome these problems.

Establishing the stratigraphic framework

The first step in the preparation of stack-unit maps is to establish a basic geologic (stratigraphic) framework of the area to be mapped. Then a standard set of formation and member names is assigned, and a unique map symbol is used to represent each unit. In some areas where a formal rock-stratigraphic classification has not been established, it may be necessary to map lithologies only (e.g., shale or upper gray, hard, clayey till) or to assign informal names, numbers, or symbols to the various materials for the convenience of the user. Although for some purposes there may be certain advantages to direct lithologic mapping, the use of standard rock-stratigraphic nomenclature whenever possible contributes to regional standardization and facilitates communication among map users and geologists.

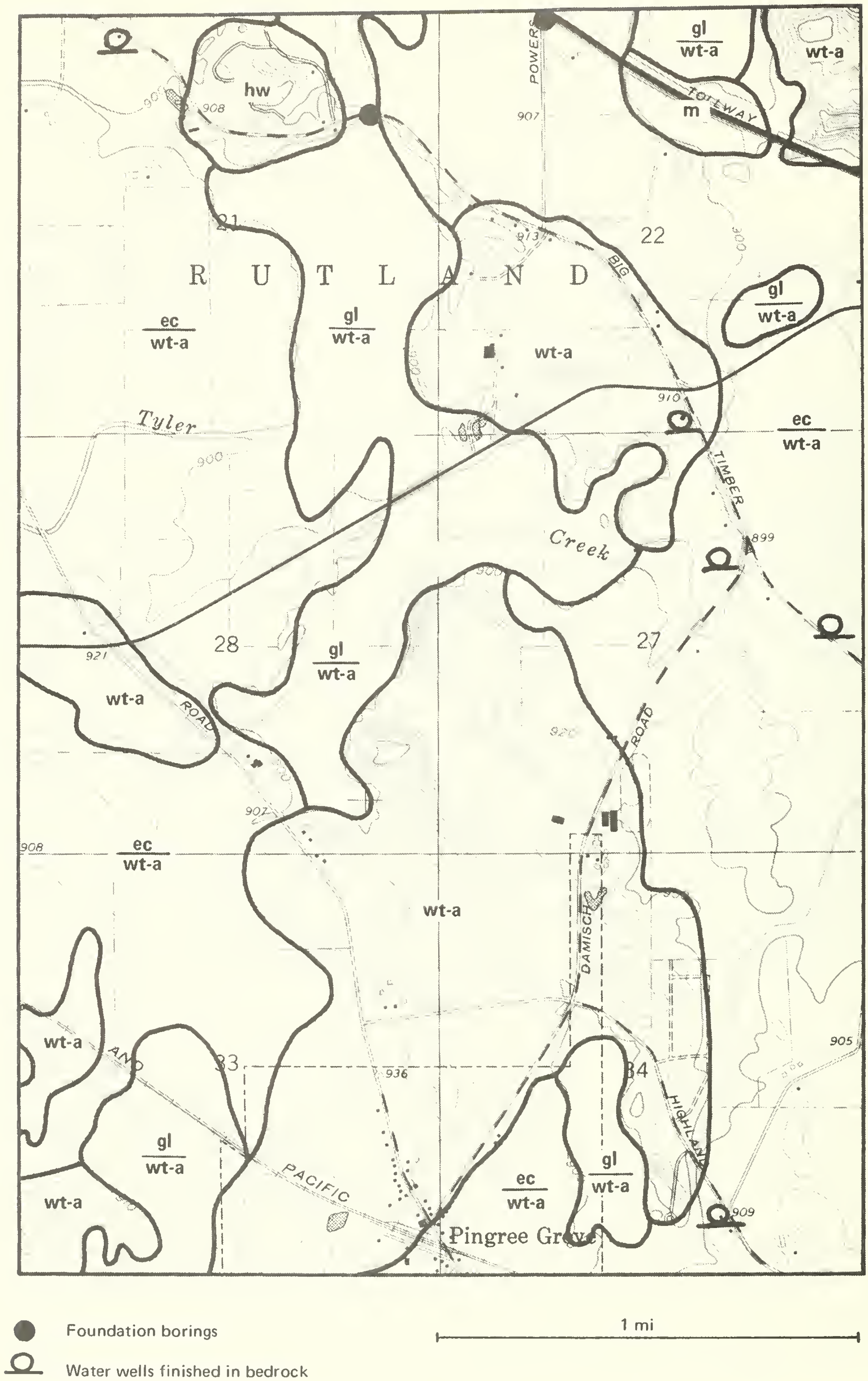


FIGURE 6. Geologic materials to a depth of 20 feet, Pingree Grove 7½-minute quadrangle (1:62,500 scale) in Kane County (Gilkeson and Westerman, 1976). See inset, figure 7.

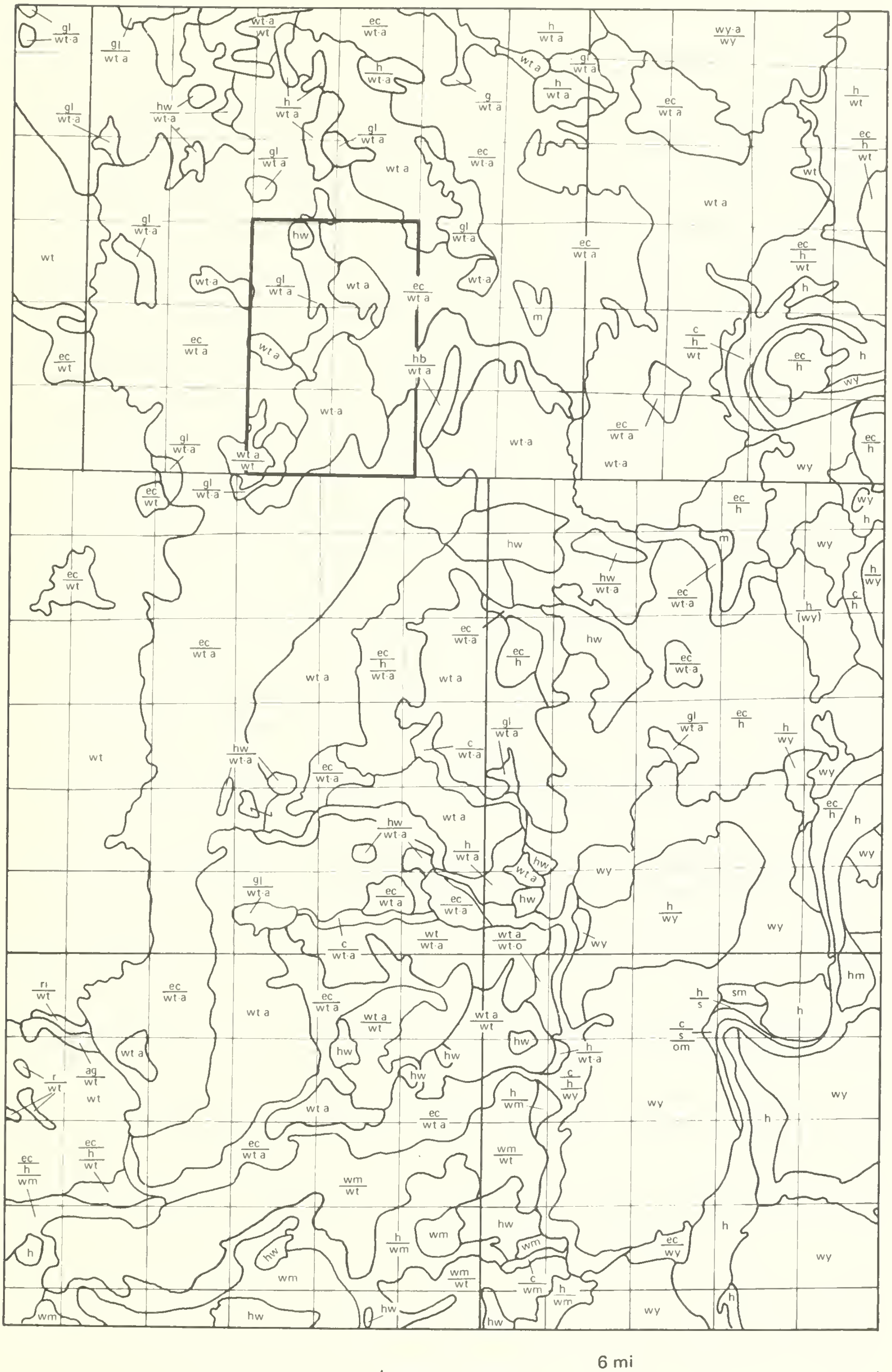


FIGURE 7. Geologic materials to a depth of 20 feet (1:125,000 scale) in part of northeastern Illinois (Kempton, Bogner, and Cartwright, 1977, plate 1).

UNIT SYMBOL	DESCRIPTION
sm	Land disturbed by extractive operations
m	Made land areas-includes major fills
py	Peyton Colluvium - slopewash along valley sides
ag	Accretion-gley - local wash, mainly silt, some organics, in poorly drained upland depressions of present surface
pl	Parkland Sand - mainly fine-grained sand of wind-blown dunes
lm	Lake Michigan Formation (undifferentiated) - fine- to medium-textured water-laid materials deposited in or along existing natural lakes
lr	Ravina Sand Member - modern beach sand
gl	Grayslake Peat - peat, muck, and locally marl
c	Cahokia Alluvium - flood plain and channel deposits of present rivers and streams
ri	Richland Loess - yellow brown wind-blown silt; thin, discontinuous on Wedron Formation and Henry Formation, frequently too thin to map
e	Equality Formation (undifferentiated) - medium-fine textured water-laid silt and clay, minor sand
ec	Carmi Member - largely bedded silt with some fine sand frequently laminated and containing beds of clay of glacial lakes
ed	Dolton Member - largely shoreline deposits of glacial lakes, mostly medium-grained sand along beaches and bars
h	Henry Formation (undifferentiated) - sand and gravel with local beds of silt; ranges from coarse gravel to fine, silty sand locally poorly sorted
hb	Batavia Member - sand and gravel deposited in outwash plains
hm	Mackinaw Member - sand and gravel deposited as valley trains
hw	Wasco Member - sand and gravel poorly sorted, deposited in ice contact hills and ridges; includes such features as kames and eskers
w	Wedron Formation (undifferentiated) - mostly till with interbedded layers and lenses of sand, silt and gravel
ww	Wadsworth Till Member - mostly gray clayey and silty clay till
wh	Haeger Till Member - mostly yellowish brown to gray brown gravelly, silty sand till

Legend for all units mapped in northeastern Illinois in figures 6 and 7.

wh-o	Sand and gravel, relatively thick and extensive, at base of Haeger Till Member and frequently exposed at surface
wy	Yorkville Till Member - mostly dark gray to brownish gray clayey and silty clay till, pebbly
wm	Malden Till Member - mostly yellowish brown to gray pebbly, sandy silt till
wt-a	Ablation phase of Tiskilwa Till Member - mostly brown and pinkish brown pebbly, sandy silt till, frequently associated with sand and gravel outwash or lacustrine silt and clay
wi	Winnebago Formation - includes glacial till and interbedded outwash sand and gravel and silt, mainly sandy and silty tills
wic	Capron Till Member - brown to pinkish gray sandy till, generally uniform texture
wia	Argyle Till Member - pinkish tan to salmon, sandy loam till
Pk	Kewanee Group (Pennsylvanian), Carbondale (top), and Spoon Formations - largely shale and sandstone with thin beds of coal, clay, and limestone
S	Silurian dolomite - Racine (top), Joliet, Kankakee, Elwood, and Wilhelmi Formations - largely dolomite, slightly to moderately argillaceous with scattered chert nodules; Racine Formation contains large reefs of massive to well-bedded pure dolomite, minor beds of shale and shaley dolomite in lower part and locally bordering reefs in upper part; partly limestone in places near Kankakee Valley; fills pre-Silurian valleys as much as 100 feet deep in Maquoketa Shale in some areas
Om	Maquoketa Group (Ordovician), Neda Formation (top), Brainard Shale, Fort Atkinson Limestone, and Scales Shale - red shale and oolite in local areas at the top; upper part largely greenish-gray shale that in places grades laterally to silty argillaceous dolomite and dolomitic siltstone; limestone and dolomite with interbedded shale in middle part; largely gray to dark brownish-gray shale in lower part
Og	Galena Group (Ordovician), Wise Lake (top), and Dunleith Formations - mostly pure, medium- to thick bedded, yellow-gray to tan dolomite above; thinner bedded, slightly less pure, and locally cherty dolomite below; limestone mottled with dolomite locally
-l	Lacustrine sands, silts and clay interbedded within or occurring below overlying material of same formation or member
-o	Outwash sand and gravel interbedded within or occurring below overlying material of same formation or member
-t	Till interbedded within or lying below overlying material of same formation or member
-a	Ablation drift, mainly till or till-like material, thin interbedded sand and gravel and silt and clay; till normally similar to, but coarser textured than, related till (e.g., wt-a)
-b	Bars composed principally of coarse, clean bouldery gravel [in Henry Formation (e.g., h-b)]
( )	Material for which symbol enclosed probably present but discontinuous; distribution and boundaries not mappable. When lower unit enclosed, indicates unit may or may not be present within 20 feet or less of surface but does occur below 20 feet.

Collecting and using data

Field observations on the occurrence and distribution of geologic materials, water well logs and samples, engineering boring logs and samples, controlled drilling at selected locations, and geophysical studies all provide data useful for establishing the rock-stratigraphic (lithologic) framework necessary for three-dimensional mapping. This information is most useful when it is compiled on topographic maps. Physical data, and frequently mineralogical data, can also help characterize the geologic units present. Since in many areas geologic units can be correlated with certain groups of soils, pedologic soil maps are extremely useful for determining the boundaries of surficial materials. Where such correlations can be made, boundaries on the geologic map are usually as detailed and accurate as soil-map boundaries.

Determining depth limit

The depth limit selected for a particular mapping project depends on the intended use of the map, on how much reliable data exists down to the specified depth, and on how well this data is distributed throughout the area to be mapped. As a rule, the depth to which the most reliable map can be prepared to give maximum benefit for a specific purpose is the most practical depth limit to which the area should be mapped (in Illinois, 20 ft [6 m] seems to be a rather practical mapping limit). However, the intended use of the map should be the principal basis for selecting the depth limit. For example, if the map is to be used in making an assessment of the pollution potential of waste disposal practices at various sites, a depth of at least 50 ft (15 m) would be desirable: this depth would allow for recognition of any sand and gravel or bedrock aquifers within the minimum thickness of non-aquifer materials considered necessary to provide protection from contamination of ground water within the aquifer. For many other purposes, mapping to depths considerably less than 50 feet is generally quite adequate.

For instance, in De Kalb County (Gross, 1970), 20 ft (6 m) was a practical depth to map, partly because much of the county was underlain by thick, uniform, glacial till. Even though the most definitive subsurface data was frequently available to less than 20 ft, the overall uniformity of the geologic conditions permitted geologists to be reasonably confident about the definition of the materials within the upper 20 ft. This suggests that, to a certain degree, the uniformity of character, distribution, and thickness of geologic units present could frequently be the deciding factor as to the practical depth limit. As illustrated in the De Kalb County study, one till (fig. 2, unit 6) that covers a substantial portion of the county averages

more than 60 ft (18 m) thick. Since the till is quite uniform in all its characteristics, mapping to a depth of at least 50 ft in sizable areas of De Kalb County would be quite practical and reasonably accurate.

In contrast, Gilkeson et al. (1977) determined that 7 ft (2 m) was a practical depth limit for their surficial deposits map (fig. 8) of a small area in Ogle County that contained an uncontrolled waste disposal site. In this area bedrock was generally less than 7 ft deep in the critical area. In the final analysis, judgments about the depth limit imposed must be evaluated on a project-to-project basis.

Establishing criteria for defining stack units

A three-dimensional map unit must represent a unique vertical succession of mappable rock-stratigraphic and soil-stratigraphic units down to the depth limit selected. Since this unit is typically shown as two or more units placed one on top of the other, it has been informally referred to as a "stack unit."

Boundaries of a stack unit shown on a map are determined by any change in occurrence of one or more of the units included in the stack for any reason (such as thinning, thickening, wedging out) that changes the vertical succession of the units shown. The sequence within each stack unit is therefore significantly different from the stratigraphic sequence in directly adjacent units.

All such units shown on a map must be fully explained on that map; however, units that are thin and relatively insignificant (relative to the mapping depth selected and the purpose of the map) are not shown. Generally, stratigraphic units less than 3 ft (1 m) thick would not appear in the sequence if the mapping depth were 20 ft (6 m). Unmapped units of potential significance can be grouped into larger units and discussed in the legend or text in order to reduce the complexity of the map without impairing its overall usefulness.

Symbols for stack units (the standard rock-stratigraphic and soil-stratigraphic letter symbols as used on the Quaternary deposits of Illinois map [Lineback, 1979] or by Bergstrom et al. [1976] in fig. 4) are arranged in a vertical sequence. The symbols for each unit are separated from those above and below by a horizontal line. A stack with 1, 2, 3, or 4 symbols is considered complete and represents the mappable units present from the ground surface to the selected depth within a defined areal boundary.

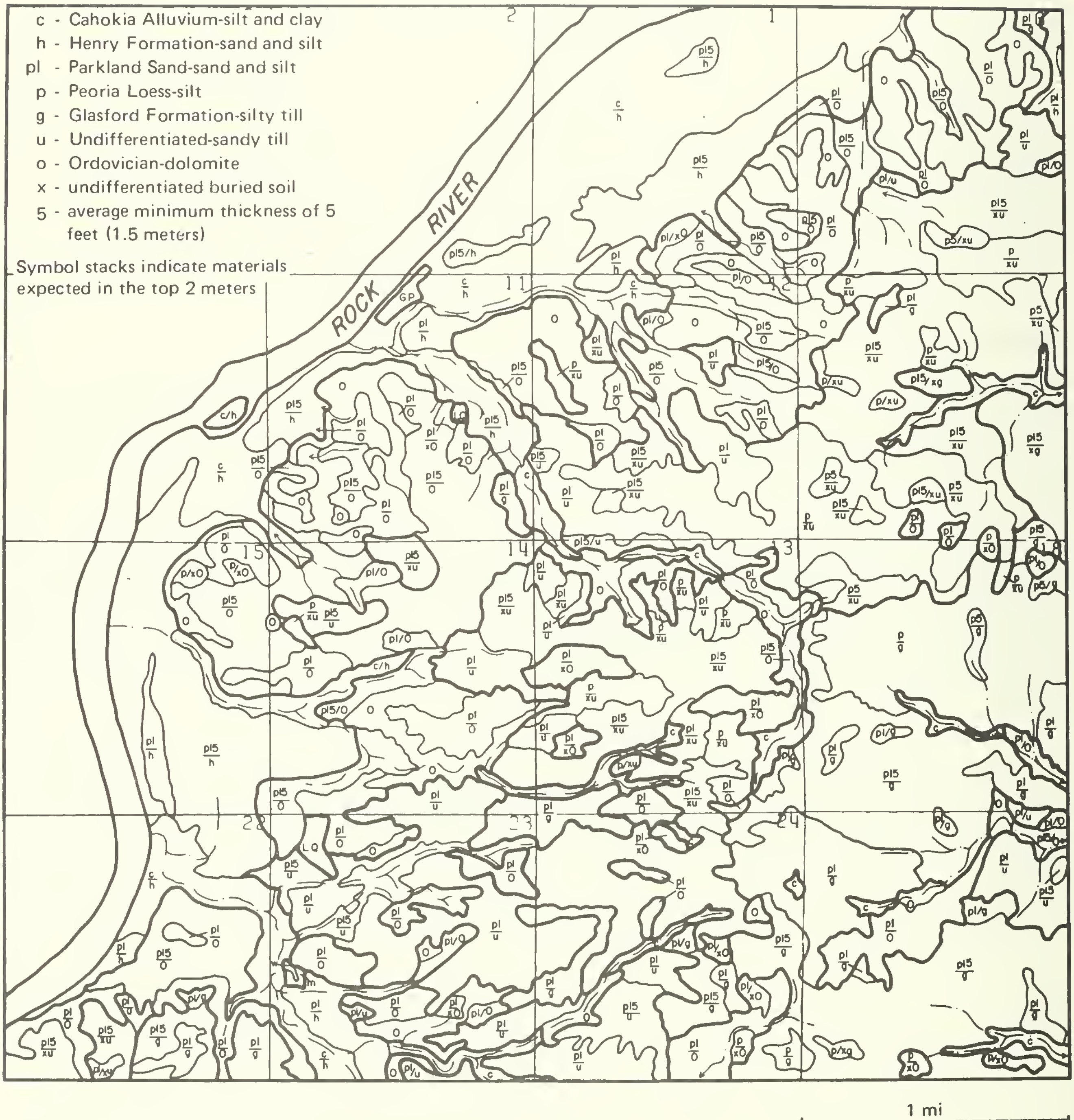


FIGURE 8. Surficial deposits of Byron area mapped to 2 meters (Gilkeson et al.).

Examples of stack units:

c	Cahokia Alluvium (1 unit, at least as thick as selected depth)
$\frac{c}{h}$	Cahokia Alluvium over Henry Formation
pr / zs / gv	Undifferentiated Peoria Loess-Roxana Silt over the Sangamon Soil developed in Vandalia Till Member (Glasford Formation) with unweathered Vandalia below.
pr / zs-gha / gv	Peoria Loess-Roxana Silt over Sangamon Soil developed completely in Hagarstown Member (Glasford Formation) over unweathered Vandalia Till Member (Glasford Formation)
sm / P	Strip mine spoil over Pennsylvanian bedrock
wm / wm-l	Malden Till Member (Wedron Formation) over lacustrine sediments included in the Malden
wt-a / wt	Ablation drift on Tiskilwa Till Member (Wedron Formation)

As a rule, a sequence of the fewest possible units (rock- or soil-stratigraphic) in any stack unit is the most useful. Possible limitations to the number of stack units mapped in a given area should also be sought to avoid distracting detail. Certain conventions have been developed to help keep stack-unit maps as simple, yet as informative, as possible.

Using conventions with stack units

During the preparation of stack-unit maps for northeastern Illinois (figs. 6, 7), it became apparent that the rock-stratigraphic framework established by Willman and Frye (1970) needed modification to fit certain stratigraphic situations that were being encountered in mapping the deposits of that area. Since it was not considered desirable to formally modify the classification, several conventions were adopted that would allow the use of the established stratigraphic units, yet avoid the need for formal redefinitions or naming of new units. With the use of these conventions, the classification was found to be quite adequate for stack-unit mapping.

The principal conventions that have evolved for use with stack units (figs. 2-8) are illustrated by the following examples:

- add informal lithologic distinctions to an existing member or formation —by use of hyphens.

wt-a

Wedron Formation, Tiskilwa Till Member—ablation drift phase.

- indicate that a unit is present at the surface or within a stack sequence, but discontinuous and unmappable, or that the continuity of a unit cannot be verified on the basis of available data—by enclosing the symbol for that unit in parentheses.

$$\frac{\mathrm{(ri)}}{\mathrm{wt}} \quad \text{or} \quad \frac{\underline{\mathrm{ri}}}{\frac{\mathrm{(wt\text{-}a)}}{\mathrm{wt}}}$$

Richland Loess, thin and patchy, over Tiskilwa Till Member; or, Richland Loess over Tiskilwa Till Member (ablation phase), thin and patchy, over Tiskilwa Till.

- indicate that a unit may be just within, at, or just below the depth limit mapped—by use of parentheses on the lower unit.

$$\frac{\mathrm{wt}}{\mathrm{(wic)}}$$

Capron Till Member, Winnebago Formation, underlying the Tiskilwa Till within, at, or just below the depth limit established.

- indicate buried soil developed in a specific unit—by using the soil designation z with the symbol for the named soil over the unit in which it is developed.

$$\begin{array}{c}\underline{\mathrm{pr}}\\ \underline{\mathrm{zs}}\\ \mathrm{gv}\end{array}$$

Peoria and Roxana Loess over the Sangamon Soil developed in the Vandalia Till Member of the Glasford Formation. This convention can also be used for the Modern Soil (zm).

- indicate actual thickness or thickness range of a formation or member mapped—by giving actual values on the map or explaining in a legend.

$$\frac{\mathrm{ri}\ 2}{\mathrm{wt}} \quad \text{or} \quad \frac{\mathrm{ri}\ 5}{\mathrm{wt}}$$

Richland Loess 0 to 2 ft thick over Tiskilwa Till; or Richland Loess 2 to 5 ft thick over Tiskilwa Till. System should be explained in the legend.

Some of the conventions are designed for a specific area, representing an accommodation to the conditions and data available in that region. Modifications or additions may be necessary in other glaciated areas or where other kinds of geology prevail.

Preparing stack-unit maps

The general procedure for preparing a stack-unit map (Bogner, Cartwright, and Kempton, 1976) is illustrated in figure 9. Figure 9a is a hypothetical section of the northern Des Plaines River valley which contains both valley train outwash (hm) and modern alluvium (c) in a valley cut in till (ww); figure 9b is a hypothetical upland area in north-central Kane County where glacial deposits consist of a complex of till (wt), ablation drift (wt-a), outwash plain (hb) sand and gravel and kame (hw) outwash and peat (gl).

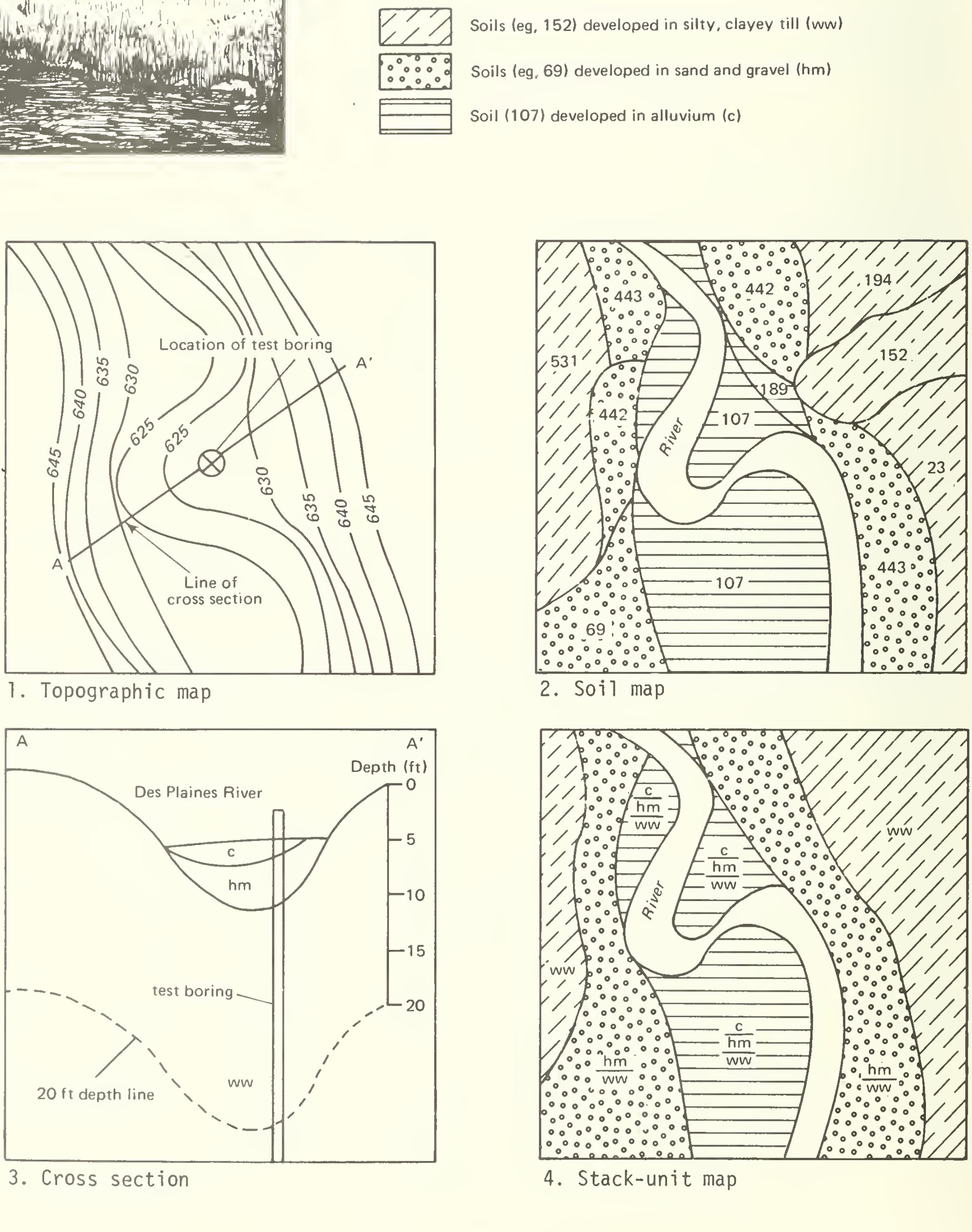
The general procedure for preparing a stack-unit map (illustrated in fig. 9, 9a) can be summarized as follows:

Step A *Collect field and subsurface data and obtain existing maps of the area.* Sketch (9a) shows local terrain. (The collection of the data has already been described in detail.)

Step B *Assemble the most recent USGS topographic quadrangle maps of the area to be mapped and, at the scale selected, plot existing surface and subsurface data; prepare thickness maps if necessary.* The scale of the topographic base maps selected depends on (1) how the map will be used--planning agencies, for instance, e usually prefer the largest scale possible unless regional planning over a large area is involved; (2) the quality and quantity of the available data; and (3) the complexity of the geology. In areas for which topographic quadrangle maps are unavailable, USGS orthophoto quadrangles at 1:24,000 might be obtainable. Recent topographic quadrangle maps supplemented by areal photographs or satellite imagery generally provide the most effective base.

Step C *Sketch or visualize cross sections through the area of interest, using available data.* This step involves working out the details of the rock-stratigraphic framework of the area being mapped and establishing the legend for all materials or rock units encountered in the area. At this point some preliminary maps are usually prepared, such as contour maps drawn on the surface of a particular unit or marker horizon, and a thickness map showing the depth from

Local terrain



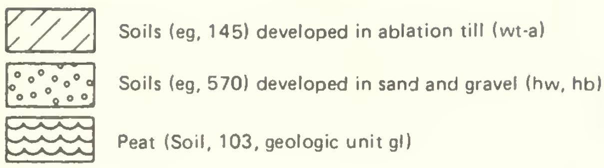
1. Topographic map

2. Soil map

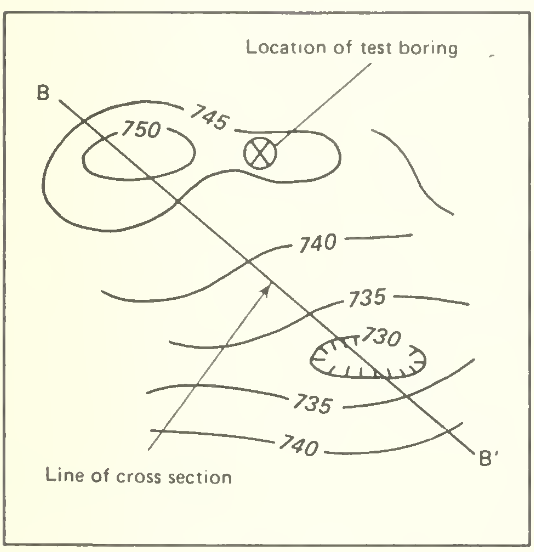
3. Cross section

4. Stack-unit map

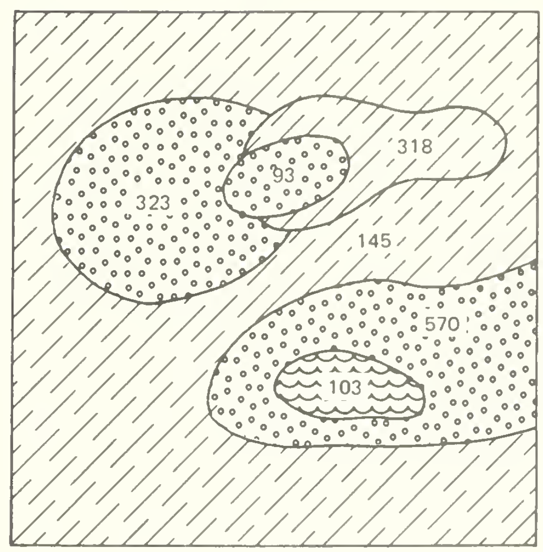
FIGURE 9a. Sequences in development of stack-unit maps (Bogner, Cartwright, and Kempton, 1976) in hypothetical area along Des Plaines River, Will County.



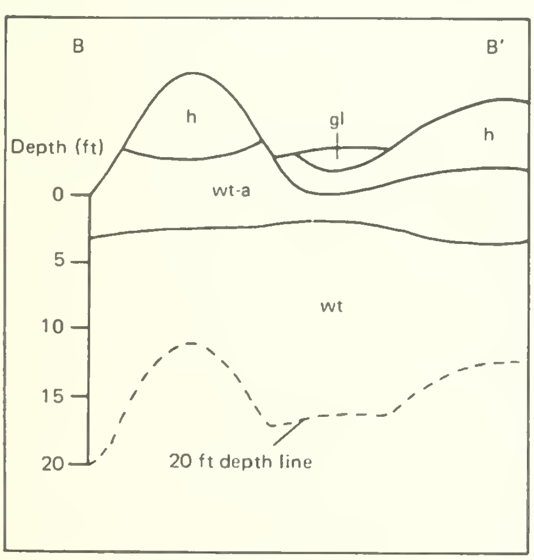
Local terrain



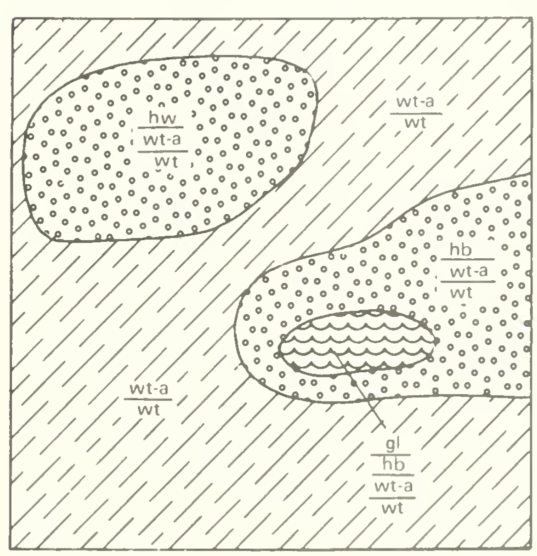
1. Topographic map



2. Soil map



3. Cross section



4. Stack-unit map

FIGURE 9b. Sequences in development of stack-unit maps (Bogner, Cartwright, and Kempton, 1976) in hypothetical area in north central Kane County.

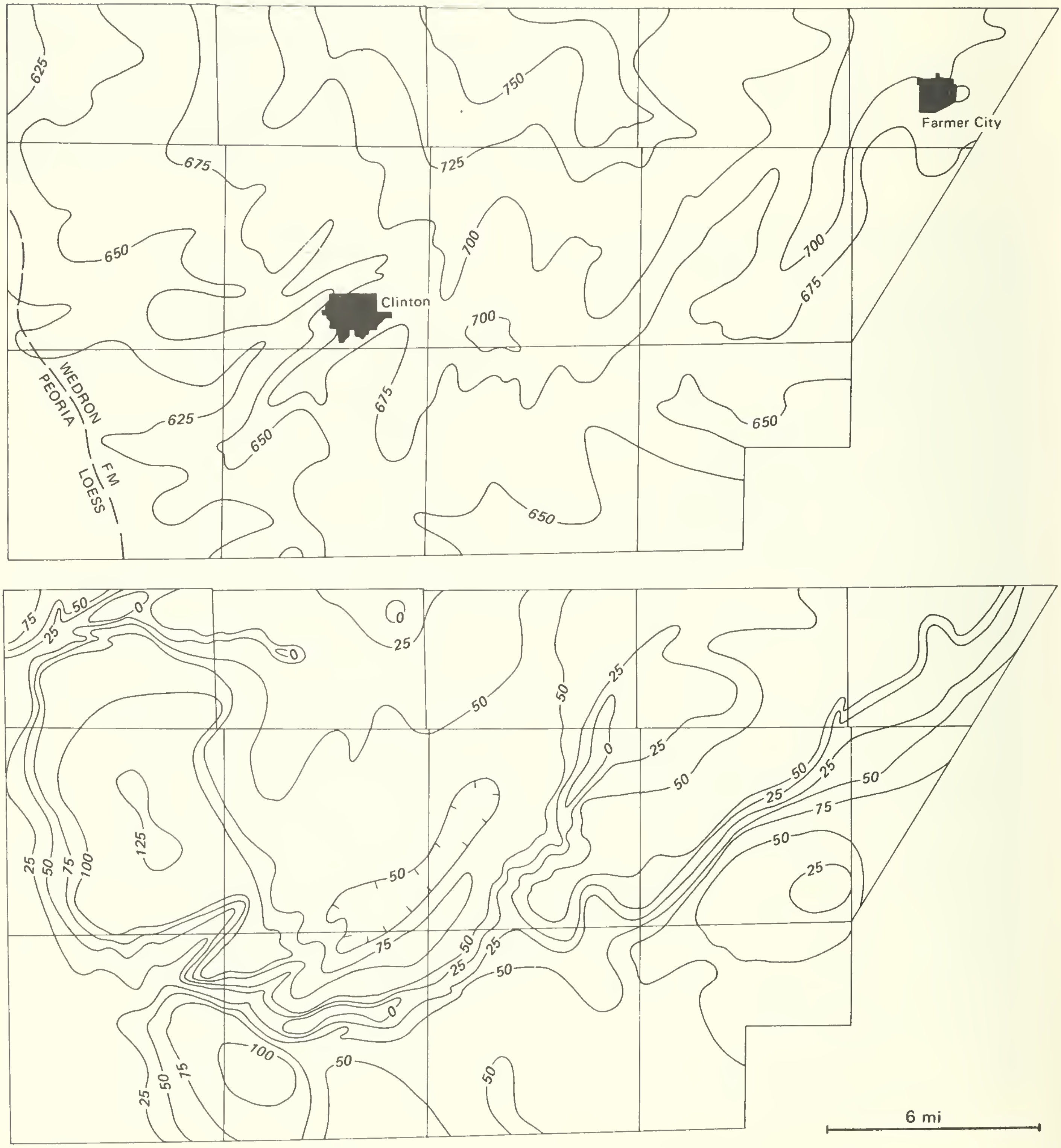


FIGURE 10. "Structure" and thickness maps used for determining depth to marker units: (a) elevation top, Robein Silt (position), De Witt County; (b) thickness of materials overlying Robein Silt, De Witt County.

land surface to the top of that unit or the base of the overlying unit. A set of such maps (fig. 10) was used in the preparation of stack-unit maps for De Witt County (fig. 5).

Step D *Collect the most recent soil information available and coordinate details of the surficial materials (as determined from pedologic soil maps) with the geologic framework.* At this stage it may be desirable to collect additional data or conduct some field checking. (If there are no published soil survey maps of the area, check with the USDA Soil Conservation Service.) Compile the mapped soil series into parent material groups. When a soil survey for a specific area is completed, the soils derived from each parent material can be grouped into sequences of soils that define the distribution (boundaries) of each geologic unit. A detailed geologic map is then drawn, using the boundaries of soils developed from each parent material as the boundaries of that surficial geologic unit. If soil data seems to conflict with geologic data (this is likely to happen in areas where geologic conditions are complex and difficult to generalize), the geologist and soil scientist will have to conduct additional field and laboratory studies and work together to resolve the problems. Such cooperation can result in a map that includes the detail routinely achieved in soil maps, and a soil map that includes the dimension of depth contributed by the geologic input.

Step E *Add the deeper units to the map (once the boundaries of the surficial units have been determined) to form the complete series of stack units.* Areas underlain by only one unit that extends to the depth limit or below are usually mapped first, then the areas with two units, and so on, until mapping has been completed for the entire area.

PRESENTING THE STACK-UNIT MAP IN FINAL FORM

The problems of preparing stack-unit maps in their simplest form are relatively small in comparison with the difficulties encountered in putting them into final readable, interpretable form. Most ISGS stack-unit maps have been published without color (fig. 1-4, 6-8). Figure 5, published originally in color (Hunt and Kempton, 1977), is just as readable when pattern is used instead of color because the geology of the area mapped is not particularly complex and the published scale is relatively large. (This map would be considered a unitized map [Varnes, 1974]). However, when there are many stack-

unit combinations in a relatively small map area, both color and pattern may have to be used to present the geologic relationships in a readable form.

Map unit complexities and the scale problem

Prohibitive cost and mechanical limitations of printing companies have traditionally been deterrents to printing the large-scale maps considered most useful for some purposes; such production problems are magnified with the increased detail necessary in stack-unit maps. For instance, in the NIPC study (figs. 6, 7), the basic mapping, at a scale of 1:24,000, allowed for considerable detail to be included. Some quadrangles contained more than two dozen individual stack units, and four geologic units are shown in several of the stack units. In some cases, the areal extent of the stack unit was too small to show on the map; therefore, when the map was reduced to the regional scale (1:125,000), it became difficult to interpret.

Another example of the scale problem is illustrated by figure 11: although the preliminary large scale mapping allowed for much detail to be included (fig. 11a), significant generalization became necessary when the scale was reduced (fig. 11b). For this reason, large areas may frequently have to be shown as complexes of several units, particularly when there are striking changes in topography. In figure 5, for example, large areas of upland and valley walls along the principal streams are mapped as a complex of several units, with the sequence of units implied by the stack-unit symbol and the local variations described in the map-unit legend. If the final scale were large enough, each of the specific sequences implied or described could probably be shown on the map. Mapping complexes rather than single units can be useful when the general sequence and occurrence of the geologic units are known but detailed mapping has not been possible. In such cases, small scale maps may be more accurate.

Use of color and pattern

Geologic maps printed in color are much more desirable—from the standpoint of immediate impact and general readability—than those printed in black and white. The regional NIPC map (fig. 7) is useful as an outline for supplying information on individual locations; but lacking color or pattern, it has little regional impact. Varnes (1974) suggests that a simple method for showing that one unit rests on another is to print a pattern or halftone color representing the upper unit over the pattern or color representing the lower unit. However, this procedure becomes impractical when more than two units are present in the stack sequence. Many variations of color and pattern can be used in the presentation of stack-unit maps, but ultimately the final presentation will be determined by the complexity of the geology, intended use, and publication cost factors.

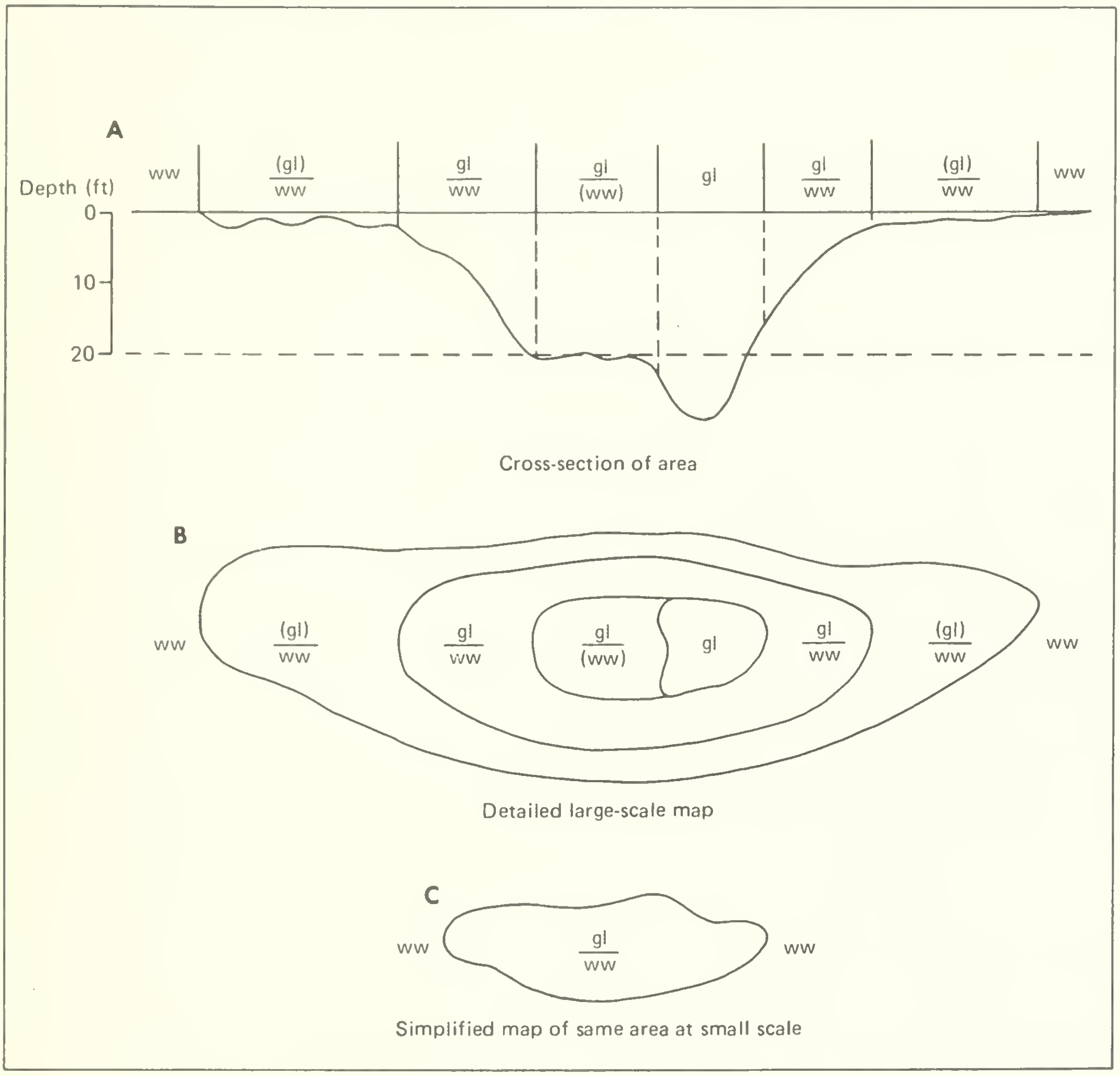


FIGURE 11. Detailed vs. simplified stack-unit maps.

USES FOR STACK-UNIT MAPS

Geologic interpretation

The stack-unit map is primarily a geologic map, providing information on the composition and general form, thickness, and extent of each mapped geologic unit within the depth limit established. But once the spatial arrangement of geologic deposits is established (primarily on the basis of observable and/or measurable physical and mineralogical properties), geologic units can be

evaluated in terms of their mineral resources and their engineering and hydrogeologic properties. In addition to providing very specific information for land use and resources development, stack-unit maps, which integrate subsurface data, can provide clues to many significant aspects of geologic history (such as limits of glacial advance, glacial drainage patterns, and the existence of glacial lakes) that occurred prior to events represented by the surficial materials. Thus the stack-unit map can sometimes provide a better key to geologic history than can a conventional surficial deposits map.

Interpretations for applied uses

Any interpretation made from a geologic map must be expressed in terms of probability; the local variability of the earth's rocks and materials, the limitations imposed by the mapping scale, and the usually erratic distribution of available data all tend to reduce the accuracy of the maps to some degree. Because an interpretative map prepared from a stack-unit map is somewhat generalized, such a map must be considered as only a guide, with the understanding that additional on-site studies will be made. For most land-use and resource interpretations, depth is an important factor: in evaluating waste disposal and land treatment practices, the depth to which contaminants can move and contaminate aquifers must be considered; in evaluating mineral resources, thickness of overburden as well as thickness and quality of the resource must be considered.

Waste disposal. The two major types of waste disposal at land surface are burial and surface spreading. The most common form of land surface disposal is the burial of household refuse in trenches 20 ft (6 m) or more deep, usually in relatively impermeable material. Relatively impermeable material should also separate the bottom of the trench from any potential aquifer below.

For evaluation of potential sites for land burial of waste, a stack-unit map prepared to a depth of at least 50 ft (15 m) would be most desirable; however, a map to 20 ft (6 m) can be used for identifying areas suitable for trench development that can later be evaluated to greater depths.

For evaluation of land for surface spreading of wastes and septic systems, a stack-unit map to a depth of 20 ft (6 m) can provide information on acceptance characteristics (permeability, etc.) of the earth materials and the pollution potential of the wastes.

In planning for the disposal of toxic or radioactive wastes, large areas and much greater depths must be evaluated both geologically and hydrogeologi-

cally to make certain that such wastes do not contaminate the surface water and ground water.

Land treatment. Fertilizers, herbicides and insecticides, and other soil additives may cause some contamination of ground and surface waters, particularly when over-applied. Stack-unit maps to a depth of 20 ft (6 m) can usually establish the occurrence of any shallow aquifers that could become contaminated and indicate whether the surficial materials have characteristics that might cause the contaminants to stay on the surface, possibly leading to pollution of rivers and lakes.

Construction (engineering) conditions. Stack-unit maps can provide data for use during the site selection stage of engineering projects such as construction of factories, power plants, dams, commercial buildings, and highway bridges, for development of areas suitable for borrow pits, and for general construction such as pipeline and sewer excavations, roads and highways, and houses.

Exploration and site investigations are routinely made prior to the construction of large structures such as power plants and high rise commercial buildings to determine those geological units that can withstand the bearing load applied by each structure and to identify any problems peculiar to the specific project. Since the depth to geologic materials competent to withstand the required pressure loads may vary widely throughout some areas, actual site selection may be facilitated by evaluating the geology regionally. It is at this stage that the stack-unit map can be particularly useful.

Information provided by stack-unit maps can also be useful for many smaller construction projects (houses, sewers, etc.) in which the natural conditions that must be contended with pose some limitations. Stack-unit maps with depth limits within 15 to 30 ft (4.5 to 9 m) can be quite useful here, since much general construction and most borrow extraction occur within this range, and problems such as poor drainage, seepage, low bearing strength, and shallow depth to bedrock can be countered by proper design and engineering practices. Surface drainage, ground-water movement, flooding, and other geologic hazards must also be considered.

Development of mineral resources. Stack-unit maps can provide information useful in locating and developing mineral resources in Illinois, such as sand and gravel, clay, and limestone (or dolomite). Because the economics of extracting minerals is determined by the thickness of overburden as well as the

thickness and quality of the resource, excessive overburden may often be a limiting factor in resource development. Stack-unit maps including individual unit thickness within each stack unit are useful for this purpose. Since economic factors and technology continue to change, interpretive maps rating the potential for development of such resources may need modification from time to time; however, they can all be based on the same stack-unit map.

Maps with a depth limit of up to 50 ft (15 m) would probably be most useful for evaluating limestone and sand and gravel resources. Current maps with a depth limit of 20 ft could be used to establish areas where the resource occurs at currently extractable depths; additional site evaluations would then be made to verify total thickness and quality characteristics.

Interpretive maps for ground water based on the stack-unit concept are rather difficult to prepare. Criteria for such maps may require information about aquifers at depths of 2000 ft (610 m) or more, unless the purpose of the map is to show the occurrence of shallow aquifers only. Although specific stack-unit maps have not been prepared to such depths in Illinois, the general distribution and depth of the major drift and bedrock aquifers are known. Therefore, by establishing areal rating systems or by grouping aquifer and nonaquifer units into megaunits for use in stack-unit sequences, it would be possible to outline the overall ground-water conditions, even to depths of 2000 ft on one map (Hackett and McComas, 1969, plate 2A; Gross, 1970, p. 12-13).

In some areas, stack-unit maps to a depth limit of 20 ft can yield information useful for evaluating conditions for the pit method of artificial recharge of ground water and for developing shallow ground-water supplies. However, other factors such as the location of the selected site relative to surface water supply and position within the regional ground-water flow system must also be considered.

Interpretive maps to be used for assessing mineral resources such as coal, clay, peat, and special sands can sometimes be mapped within units included in stack-unit maps. Wherever resources lie within the practical depth limit of a stack-unit map, such resources can be outlined directly from the map.

Coordination with pedologic soil maps

The most accurate maps of surficial materials are produced through coordinated mapping of geology and soils; such integration of data significantly

reduces the possibility that data from one discipline will be misinterpreted by the other discipline (McComas, Hinkley, and Kempton, 1969).

Soil maps are widely used as a basis for local and regional land-use de-decisions related to urban development in addition to agricultural purposes. Interpretations showing water-related hazards and limitations of soils for development of septic tank absorption fields or for buildings and foundations are routinely made for each soil type. Interpretations made primarily from geologic data (for example, the pollution potential from surface spreading of wastes) must include the mitigating role of the soil in reducing the quantity of contaminants that may move into shallow aquifers. Since the depth dimension must be considered for all these purposes, the combined use of stack-unit maps and soil maps provides the basis for a complete evaluation for many land-use and resource studies and avoids the possibility of conflicting interpretations based on only one information source.

POTENTIAL LIMITATIONS TO STACK-UNIT MAPPING

Several factors may limit the accuracy and usefulness of stack-unit mapping: lack of data; scale problems; complex geology; extreme topographic relief in areas to be mapped; and problems of presentation and printing.

Lack of data

The preparation of stack-unit maps depends on the availability of a large quantity of reliable data to the established depth limit, well distributed throughout the area to be mapped. Samples of the various units mapped should also be available so that the properties of each unit can be adequately characterized. Unless a soils map is available to aid in outlining the boundaries of surficial materials and verifying their occurrence, a considerable amount of additional field mapping may be necessary. Field study and mapping of all available exposures, along with topographic evidence, frequently provide the most accessible data. Other sources of data include published and unpublished reports and maps made by areal photography and/or satellite imagery. Regional information from structure maps can sometimes give additional information on a particular unit to supplement limited local data.

Scale problems

Maps are useful only when presented at a scale appropriate for their intended use. For many land-use and resource interpretations, the largest scale

possible is best—however, the larger the scale, the greater the implied accuracy of the map. In Illinois, the scale of the U.S. Geological Survey 7½-minute topographic quadrangle maps—1:24,000 or approximately 2½ inches = 1 mile (4 cm = 1 km)—is most useful for most needs. These 7½-minute maps also provide good topographic reference for mapping surficial deposits. However, the fact that specific cultural features (buildings, roads, and streams) can be easily and accurately located on such maps implies to some users that geologic boundaries placed on the maps are just as accurate, which is not necessarily the case. Furthermore, within the boundaries of any given stack unit mapped, it is also implied that all material units shown in the stack unit are present within the depth limit assigned anywhere within the boundary, and that no other units will be encountered to the depth limit within the boundaries.

Therefore, it is obvious that some reasonable disclaimers should be made as to the nature and accuracy of the boundaries and to the overall accuracy of the map at the scale used. One of the temptations of map users is to enlarge a map (thereby enlarging the scale), implying that the original mapping was done at that scale. In most instances, however, scale reduction is a valid procedure which does not decrease the relative accuracy of a map. Reducing map scale or doing the original mapping on a smaller scale map may require the use of more general information (formations instead of members) for the components of the stack units. If such information still satisfies the basic purpose of the map, then the small scale map will still be useful.

Complex geology

One of the factors that can limit the accuracy of a stack-unit map is the type of geology being mapped. In Illinois, two types of areas are particularly challenging from a mapping standpoint: (1) in northeastern Illinois, glacial deposits are often more than 200 ft thick, local relief is moderate, and glacial and glacial-related deposits vary widely in areal distribution and vertical sequence; (2) in northwestern Illinois, loess thickness is variable, glacial and glacial-related deposits are thin and patchy over bedrock, and local relief is generally high.

In northeastern Illinois, fairly accurate stack-unit mapping has been possible because a sizable amount of data is available, a stratigraphic sequence has been established for the deposits of the region, and a few units have easily recognizable characteristics that help identify them wherever they occur. Because fairly large areas of rather clear-cut map units can be established, the major map making effort can be focused on working out the details of the more complex areas. If the identity of some units is in

doubt, a choice may have to be made between two different units with similar properties.

In northwestern Illinois, subsurface data are generally sparse and local relief is great. There is little continuity in the thickness or extent of Pleistocene materials, and exposures where more than one material cover the bedrock are rare. It has thus been difficult to establish a geologic framework on which to base useful stack-unit maps.

Geologic complexity may therefore be partly relative, the result of uncertainties due to lack of data. The capability of preparing useful, large-scale stack-unit maps is consequently limited—unless substantial time and effort are allotted for collection of detailed field and subsurface data.

Extreme topographic relief

Areas with extreme local relief are difficult to portray on stack-unit maps. The mechanics of representing stack units can be particularly complicated when units are truncated along steep slopes—which means adding or subtracting units within relatively short distances. Unless the relief is developed principally on one rather uniform material, the most accurate representation of the units present to a given depth in any specific locality may be best handled by mapping complexes (fig. 5).

Problems of presentation

One of the drawbacks to using stack-unit maps is that it is often difficult to get a good regional picture of lateral and vertical geologic patterns from what is basically an outline map with materials identified only by stacked letter symbols inside the unit boundaries. If maximum benefit is to be gained from stack-unit maps, some general guidelines will have to be developed concerning the use of relatively simple combinations of colors, symbols, and patterns for each map area; this may be best accomplished by individual mappers and dictated mainly by the specific geologic characteristics of each area mapped.

POTENTIAL FOR FURTHER DEVELOPMENT

Several strategies could be used to expand the usefulness of the stack-unit concept: (1) developing techniques to map at greater depths; (2) mapping bedrock (nonglacial) geology in unglaciated areas and in certain subdrift situations; (3) producing terrain maps by combining topography, landscape features,

and slope characteristics; (4) using large-scale site-specific evaluation for precision mapping; and (5) integrating stack units with specific soil series or soil associations from pedologic soils maps.

Mapping to greater depths

In Illinois, the deepest limit established for stack-unit maps completed or in progress has been 20 ft (6 m). However, for many areas, maps to considerably deeper limits could be produced without substantially reducing the detail of the maps or increasing presentation problems. Certain generalizations of material units may be required to extend the depth limits, and additional conventions might be needed to assure that all significant geologic units are represented. In many areas of central, south-central, and western Illinois, the thin surficial materials (mostly glacial deposits and loess) and bedrock units (Pennsylvanian) lie relatively flat, and their lithologic characteristics are fairly uniform to depths of more than 300 ft. In such areas it would appear quite practical to establish a map depth limit to 50 ft (16 m), 100 ft (32 m), or even deeper, if necessary. With the increased depth, expanded legends would probably be necessary to explain generalized or megaunits. Additional conventions could be established to indicate significant variations within megaunits (e.g., basal sand and gravel fill or buried bedrock valley). Stack-unit maps to depths greater than 20 ft will probably be more valuable than those currently in use, so long as they do not become too complex.

Mapping unglaciated areas

Although at the ISGS stack-unit maps have been developed for predominately glaciated areas, they can also be used for other types of geology. Large regions underlain by relatively flat-lying Paleozoic, Mesozoic, or older Cenozoic-age rocks should be relatively easy to map three-dimensionally. In areas where units are thick and relatively uniform in character, the depth limit could be extended to several hundred feet, yet be presented relatively simply on the map; subdrift units could be handled the same way. Conventions similar to those established for glacial deposits in Illinois could be adopted to depict the variety of sedimentary, igneous, and some metamorphic rock terrains as well as areas of complex structure. It seems likely that stack-unit mapping--in some form or other--could be used with most types of geology.

Preparing terrain maps

The goal of geologic mapping in environmental geology is to summarize, as completely as possible, the geologic factors relating to resources and land use,

integrating information about the geologic materials underlying the surface of the landscape with information on the topographic features making up the landscape. This type of composite map, called a terrain map, was prepared for McHenry County, Illinois (Hackett and McComas, 1969).

More precise mapping of geologic materials can be accomplished when the characteristics of the topography are considered; conversely, the shape and distribution of geologic materials can often be better understood if the sequence, character, and distribution of the geologic materials are known. When both form and composition of features are considered, greater regional predictability is possible in terms of the overall characteristics of the various features and the potential limitations for various uses.

Preparing detailed mapping for site studies

Intermediate and small scale stack-unit maps can provide an excellent basis for selecting construction sites and planning, in a general way, for specific projects. Large-scale stack-unit maps can be useful for summarizing the results of detailed on-site investigations. Many site investigations for major construction, waste disposal, or resource development projects generate sizable quantities of subsurface data to be used in identifying the occurrence and distribution of materials that provide adequate bearing strength, meet criteria necessary for waste disposal projects, or have certain types of resources. Interrelationships of occurrence, thickness, and properties of the units encountered are often difficult to visualize in the standard cross section or two-dimensional maps of individual units; therefore some form of stack-unit map taken to the necessary depth could possibly yield fresh geologic insight that would affect the final design plans for the project.

Incorporating soil data on stack-unit maps

The interrelationship between mapping geologic materials and surface soils has been previously discussed. Obviously, the surface soil, developed in the uppermost rock or material unit(s), is an integral part of the earth material framework. Buried soils (paleosols) are treated as such (fig. 4, 8), and the occurrence of surface soils is acknowledged but not usually included directly on most geologic maps.

Since ISGS geologists are already using modern soils maps to facilitate identification of surficial materials and their boundaries, it would seem to be a logical next step to incorporate specific information about the surface soils, when available, into stack-unit maps. This practice would be particularly valuable for local or site studies. The simplest way to incorporate soil

information onto large-scale maps is to use a number designation for a given soil with the symbol for the geologic unit in which it is developed. For example:

$$\frac{\text{zm 27}}{\text{wt}} \qquad \frac{\text{zm = Modern Soil, 27 = Miami Silt Loam}}{\text{developed in Wedron Fm., Tiskilwa Till Member}}$$

The characteristics and specific properties of the Miami Silt Loam and any other soil that would be listed are defined on individual county Soil Survey reports. (Other variations in the method of presentation are of course possible.)

For regional or small-scale maps, soil association maps might be combined with regional stack-unit maps. Direct cooperation between soil scientist and geologist is necessary in order to determine the most appropriate coincident boundaries between soil association and related geologic boundaries.

SUMMARY

Development of practical mapping techniques to present information on the three-dimensional distribution of geologic materials has significantly added to the ease and accuracy of preparing interpretive maps for evaluation of resource development, waste disposal, and land treatment practices in Illinois. At the same time, the use of such maps has facilitated interpretation of geologic features and enhanced the capability for predicting the occurrence and characteristics of geologic materials at depth as well as at land surface. As stack-unit maps are used more widely, and as more suitable methods are developed for presenting the information they provide, they will continue to become more useful as a primary source of geologic information.

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